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Education in Atomic Energy

II—WHAT DEGREE OF SPECIALIZATION?

IF NOTHING ELSE, research in the field of atomic energy during the past war certainly proved one thing: give engineers and scientists a sound grounding in fundamentals and they can transcend the borderline between fields. This is the keynote of education in atomic energy.

Basically, there is an interrelationship amongst all sciences. The theory was put forth in the 18th century that the fundamental sciences could be listed in such a fashion that each science should be dependent upon those preceding it, and independent of those which follow it. All of the sciences have in common, to a certain extent, the method of approach to, or analysis of, a problem. This is especially true in the engineering sciences.

Thus, a man who studies thermodynamics intensively in connection with machines for converting heat energy into mechanical energy is not necessarily bound to deal in his professional work merely with heat engines of one sort or another. With ability, he might later apply thermodynamics in such a field as chemical engineering. He might even grasp usefully the significance of thermodynamics in more remote fields, such as biology and statistics.

But if a man were to undergo training in a narrow specialty, he would obviously find himself rather restricted as far as opportunities were concerned. It was pointed out in this space last month that it can take from four to ten years to train a scientist, depending upon the degree of specialization. If, as is certainly very possible, a student finds his interests changed by the time he gets his degree or if the needs of his field have changed, he will find it necessary to reorient himself.

Thus, the basic question in education in engineering and the sciences is one of whether we should have broad education in fundamentals or narrow training in specialties.

The atomic energy field provides an excellent "workshop" for evaluation of the pertinent factors. Here, we find one technical field having considerable effect on just about all others—biology, medicine, physics, chemistry, metallurgy, etc. When the Manhattan District was first organized, only a very small proportion of those ultimately employed had specialized training for the job at hand. Physicists had to learn the theory and application of a

nuclear chain reaction. Chemists and chemical engineers became involved in isotope separation and materials-processing operations. Metallurgists had to develop materials to meet unusual requirements. All of these tasks were complicated by the same thing—nuclear radiation.

But these people were able to cope with the many unique problems presented them because their education was sufficiently broad.

Now we are at the point where educational institutions are beginning to recognize the impact of the various aspects of atomic energy. This is especially evident in departments of chemistry, physics, biology and medicine, where many new avenues of research have been opened. In these departments, new courses have been added to existing curricula. A chemistry major, for example, can now take optional courses in tracer chemistry and radiation chemistry at many schools.

In the case of nuclear engineering (defined as design, construction, and operation of nuclear reactors), the situation is different. A study conducted by Harvard University states that it is "probably too early" to set up instruction in nuclear engineering because the form and timing of ultimate commercial application are still very much in doubt. It must be realized, however, that if and when such curricula are set up on any broad scale, the worker in this field needs a thorough understanding of only a small part of nuclear physics, but by no means a comprehensive grasp of the entire subject. Primarily he needs a thorough training in the basic aspects of his own degree. This is well illustrated in the article by Mr. Wilbur E. Kelley elsewhere in this issue.

The problems in reactor technology are best tackled by capable chemical, electrical, electronic and mechanical engineers who can pick up the requisite nuclear physics. The contributions of nonspecialists in this field have been of prime importance. The following quote from a book review that appeared in the June issue of NUCLEONICS bears this out:

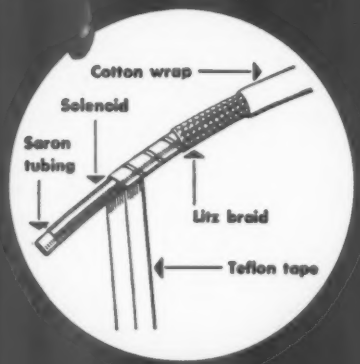
"Although a part of the National Nuclear Energy Series, this book contains no specific information on fission processes or materials. It is, instead, a collection of incidental information which was required as background material for the conduct of the more spectacular phases of the Manhattan Project. As such, it is a good indication of the vast amount and range of scientific data required to reach the major objective. It can be cited as an example of the necessity of maintaining a uniformly high research productivity in all fields of science in order to provide the means for rapid success in any one field which may become vitally important."

The key to such success is the type of engineers and scientists which our educational institutions turn out. In the atomic energy field, we hope that there will be produced a sufficient number of technical men with a sound education in fundamentals to lay the groundwork for future utilization of atomic energy.

—Jerome D. Luntz

SCIENCE NEWS FROM GENERAL ELECTRIC

delay lines



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GENERAL ELECTRIC

ENGINEERING IN THE ATOMIC AGE*

Many problems presently under attack in the atomic-energy field require application of sound engineering principles. The greatest personnel need is for good engineers with a thorough grounding in their own field, rather than for nuclear engineering specialists, as the author's examples show

By WILBUR E. KELLEY

Manager, New York Operations Office
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MY THESIS in this article is a simple one, and it has only two points: If we are to enjoy the fullness of life that Nature can provide us, we must establish close understanding between the scientist and the engineer; neither is self-sufficient. The second point of my thesis is this: Engineering today is admittedly more complicated than ever before *but it is still based upon sound and thorough understanding and application of well-known engineering principles,* the kinds of things we learn in the first few pages of the engineers' handbook.

It is the business of science to explore the mysteries of nature, the *how* of things. It is engineering that applies the basic facts, that converts the bare principles into useful things, into things that will help us do our work better, enjoy life more fully, or, if the occasion should arise, fight a war and win it.

I am not deprecating the role of basic science. These last two generations have shown the importance of a

* From a talk given at the celebration of the 25th Anniversary of Speed Scientific School of the University of Louisville, May 19.

Wilbur E. Kelley received his B.S. and C.E. degrees and D.Eng. (honoris causa) from the Speed Scientific School of the University of Louisville.

Following graduation, he joined the United States Engineers and worked on dam construction in the Upper Mississippi Valley, on flood control in Texas and, immediately prior to the war, on design of bomb-proof construction and new locks for the Panama Canal.

One of the first staff officers assigned to the Manhattan Project, Dr. Kelley was project chief and later operations chief of the electromagnetic separation plant (Y-12) at Oak Ridge.

As manager of AEC's New York Operations Office since 1947, Dr. Kelley supervises processing of uranium and other ores, procurement of special materials and devices, licensing of source materials, and administration of more than 280 prime contracts for research, development, and procurement and the operation of Brookhaven National Laboratory and the New Brunswick Analytical Laboratory.

vast reservoir of basic scientific information, and if we are to progress as rapidly as we can, we must have continuing basic investigations into the whole complex of nature. But basic science without the engineer to develop ways of applying laboratory discoveries is an empty game, an intellectual exercise.

Perfection Before Application?

We need basic investigations but today we have discoveries of facts of nature that we can't apply, and one reason we can't is that competent engineers are not being used to apply them. We seem to be following the path of achieving perfection in our understanding of a scientific fact before we make any effort to apply it by our traditional—and highly successful—way of cut and try, engineer and re-engineer, build and rebuild.

Closer Contact

The engineer needs to be brought closer to the laboratory scientist, in order both to speed the ultimate application of scientific discoveries and to assist the scientist in his work. Recently, a talented physicist was telling me of a problem that he felt sure he could solve if he had a quick and cheap way to make smooth cuts in heavy plate. He had tried the ordinary torch—he said milling was too expensive and that they lacked the equipment anyhow. He is now a happy man—we told him engineers have been using an "oxygen lance" for years for the purpose. Though a fine scientist in his field, he had never heard of it. We need closer contacts between scientists and good engineers. Many scientists who are trained as specialists in a narrow field are slow to seek help from engineers, and work suffers as a result.

Many people approach modern science and its problems as if it were a kind of magic. That isn't so! There are mysteries in nature, but there isn't any black magic. The real experts at this business are humble. They'll say there are many things we don't know, but when we learn them, they will be simple—and, when we're competent enough to explain them, you'll understand them too. For example, it is known that natural uranium can be arranged in such a way as to produce large quantities of heat that we can control. By proper manipulation that reaction can be made to produce another material—plutonium—not found in quantity in nature. This material—and a small part of natural uranium—can be used to produce either controlled power or an explosion. These are things we all know and can use. The scientists are still concerned with why or how these things happen. The engineer is needed to control and apply them.

For instance, scientists had demonstrated on a laboratory scale that by passing a uranium vapor through an arc in a vacuum in a magnetic field uranium particles could be accelerated in a circular path and the various kinds of uranium separated. By that separation, enough special uranium might be obtained to make a bomb. That process, in scientific principle, can be sketched on the back of an old envelope; but to translate that bit of scientific knowledge to practical use during the war took:

450 buildings
32,000 tons of steel
15,000 construction people
25,000 operating people
450 million dollars worth of effort
13,000 engineering drawings

and an infinite number of grey hairs!

Basic Knowledge is the Key

To the civil engineer, our present age offers challenges of all kinds—bridges of greater size—all the good locations have been used—his job is tougher. We're now designing dams on sites that would have been rejected years ago. In the

field of atomic energy, we're asking for buildings with heavy walls, with heavy steel plate laced into them. We ask for concrete and steel tanks that won't leak a single drop—ever. We want sewers that won't corrode, filter beds containing tiny organisms, that, in effect, eat radioactivity and thereby concentrate it for easier handling. We set new targets for the civil engineer, and we may teach him something new in nuclear science, but *it's his basic training as a civil engineer that prepares him for the modern world.* His ability depends upon the experiences of all the civil engineers who have preceded him. He has to add to their knowledge, but he doesn't abandon it.

The growing circle of knowledge doesn't just have a circumference; it has a center of fundamentals that can't be abandoned. It's hard to believe—yet in my own recent experience I have seen the cost and heartaches from being blinded by the dazzle of the words "atomic energy," "radioactivity," and such. I know of a job where the designers were so preoccupied with the new and unique part of the work that they forgot to provide for the expansion of steel! That's on page 4 of the handbook—*before* you get to the last chapter on atomic energy and rockets to the moon!

M.E.'s and Metallurgists

From the mechanical and metallurgical engineers, the atomic energy industry needs designs of pumps that work at higher pressures, that will handle corrosive fluids and gases with little maintenance. We need piping that won't leak, valves that are so tight that a few stray molecules will have trouble getting by. We need designs of equipment that will turn faster than the velocity of sound at extremes of high and low temperatures. We need construction materials that will be safe and strong at −450° F, and some at 4,000° F. We need equipment so simple that it can be operated and maintained from behind a ten-foot wall. We may also specify that because of special nuclear requirements the structural material for one of these gadgets must be selected from three or four elements of nature, none of which has ever been used as a structural material before. Again, we have new targets for the engineer, but he doesn't reach them by some modern and new magic, but by smart use of his fundamental training.

Electrical Engineers

Today, we call on the electrical engineer to help us design huge magnets weighing thousands of tons—and we also call on him to design a peanut vacuum tube that will operate a radar set in the nose of a rocket. At an atomic bomb test he may help us steer a pilotless aircraft through the radioactive cloud, but his art is based, too, on the knowledge of those before him. He's learned some new tricks, but he still has to remember the simple facts of resistance, voltage and current learned in school. When he forgets them, he still gets sparks just like Dad used to make. We've torn out switchgear and controls designed for atomic equipment that wouldn't have been any better hooked to a street car.

Chemical Engineers

The chemical engineer has thousands of challenges, too. We make his life more difficult by adding new requirements to old problems. We tell him that processes have to work with 99.999% efficiency. We ask for the last thousandths of an ounce of material from 30,000 gallons of solution and then tell him he can't go near the tank or see the process in action. He has to do it with mirrors! We tell him to sift the chemical gems from hot ashes and not to miss any. He has to develop ways of analyzing for one part of a material

buried in a million parts of another. These things aren't easy and there are some new tricks to help solve them, but if he's analyzing for one part per million of boron he'd better not wash his hands in borax! He mustn't get so impressed with the fascinating modern problem that he forgets the fundamentals. The science of dealing with dangerous radioactive materials is difficult to learn by practice in universities, but I learned 25 years ago that lead would shield me from gamma rays and that beta rays would burn my exposed hand. We know a lot more now about how much will do what, but it wasn't because of the newness involved that some of our boys got beta burns at Eniwetok. They forgot their gloves!

Engineers in Medicine

There are many new developments in medicine and biology—many of them made possible by the work of engineers. Doctors are now being trained by television; it's now possible for a hundred students to observe an operation by means of television cameras with repeater screens for the students. There are new ways to design replacement parts for the body—with the help of the engineer. In the special field of radioactivity we can feed a patient materials that will identify themselves as to quantity and amount as they travel through the body. In days past a doctor might have to search for a brain tumor by drilling a series of holes in the skull. Recently there has been great success in using a radioactive material that will settle harmlessly in the tumor and send out rays that can be located exactly on the outside. The engineer designs giant X-ray machines for the doctor and protects him while he uses them. Today, a large modern hospital contains non-corrosive sinks and instruments, air-conditioned operating rooms, self-leveling elevators, a refrigerated blood bank, and automatic fire fighting equipment. The doctor is taking the engineer into partnership.

Tribal Trouble

Our country is rich in resources of all kinds—including smart people—but in my experience we need to develop more. Not long ago I listened to the head of a large engineering school lament the fact that there were so many more engineers graduating than could get the kind of jobs to which their training entitled them. I know the training his school gives—and it's world renowned—but in my opinion, it's too specialized. He's turning out chiefs when what we need is more indians! Some of those indians can grow up to be chiefs—in industry.

Science is by no means completely tolerant. Its goal is to seek out the truth, and its history has been one of steady progress toward this end. If truth could not be disentangled from error, science would have no meaning. So long as a particular element of truth has not been discovered or is only imperfectly known, the seeker's mind must be completely open to help from other quarters, but once a portion of the truth has been found, has been separated from error and become a part of the intellectual capital of mankind, then the conception of tolerance to ideas incompatible with it quite loses meaning. Tolerance of what has been proved to be untrue is manifestly absurd. Thus science builds an ever growing body of certainty, of assured and proved truth.

—*Edmund W. Sinnott*, Science **111**, 123 (1950)

USE OF THE PILE FOR CHEMICAL ANALYSIS

In two-component systems, elements that are sometimes difficult to identify reveal themselves readily after bombardment by nuclear radiation. Any laboratory with a pile, cyclotron, betatron, or linear accelerator can make such analyses. As discussed here, the pile is the best instrument for the job

By C. O. MUEHLHAUSE and G. E. THOMAS
Argonne National Laboratory, Chicago, Illinois

OF THE MANY physical methods that may be used to identify the chemical elements, the most sensitive are those that exploit the properties of nuclei. For example, the nuclear radiations that can be induced by bombardment with neutrons, protons, deuterons, alpha particles, or gamma rays readily serve as detectors of the activated atoms. In the simple case of β^- radiation (induced by a very high neutron flux and detected by a Geiger counter), as few as 10^{12} atoms can be detected. This number (for average atomic weight) corresponds to 2×10^{-9} gm.

Methods of chemical identification involving these particle or photon irradiations may be applied in radiation laboratories having one of the following instruments:

1. Pile (*neutrons*)
2. Cyclotron (*protons, deuterons, alpha particles, neutrons*)
3. Betatron (γ-*rays, neutrons*)
4. Linear accelerator (*protons, neutrons, deuterons*)

There are many laboratories now existent that can use the "nuclear analysis" method to make rapid and sensitive chemical identifications. In the United States, these laboratories fall into two groups: (*1*) Atomic Energy Commission laboratories that have piles, and (*2*) institutions that have cyclotrons, betatrons, or linear accelerators.

This paper will be concerned with those methods of "nuclear analysis" available in neutron radiation laboratories (i.e., piles). However, the methods outlined, and others similar to them, may be applied also in any of the other radiation laboratories (i.e., cyclotrons, etc.)

NEUTRON IRRADIATION PROPERTIES

Neutron-induced Radiations

Before discussing separately the types of radiation induced by neutrons, we shall consider some radiation intensity factors.

In general, when a small amount of a substance to be detected is irradiated in a pile neutron flux, the resulting intensity of activation, I, as measured by a given detector, is determined by the following factors:

n—number of atoms in units of 10^{24}. The activity induced is directly proportional to this number.

f—pile flux. The number of pile neutrons per cm^2 per sec is a proportionality factor of the intensity of the induced activity.

σ_p—pile activation cross section in units of 10^{-24} cm^2 (barns). This is the effective area per normal atom for absorption

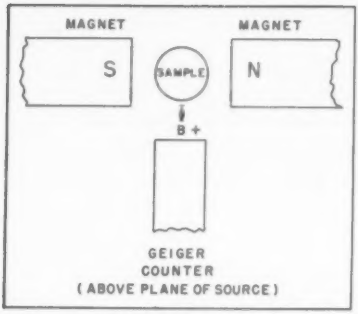

FIG. 1. Simple scheme for detecting β^+ particles. A strong permanent magnet is used to separate β^+ from β^- radiation

and consequent activation of the isotope by means of which the substance is detected. It, likewise, is a proportionality factor of the intensity of the induced activity.

ϵ—detection efficiency. This too is a factor that determines the constant of proportionality of the measured intensity.

T—mean life of the activity. Unless the bombardment time, T_B, is long relative to T, both T and T_B determine the intensity of the induced activity.

Collecting all these factors into one formula yields:

$$I = \epsilon n \sigma_p f (1 - e^{-\frac{T_B}{T}})$$

When the material is bombarded to saturation ($T_B >> T$), this formula reduces to:

$$I = \epsilon n \sigma_p f$$

In the following sections, the activities will be assumed to be saturated, and detection limits will be given in terms of atoms per barn (10^{-24} cm^2, one unit of σ_p) per neutron flux of 10^{10} per cm^2 per sec. The limit of detection is determined by the typical background of the detecting instrument. The background current or counting rate represents the smallest practical intensity that can be measured. We shall therefore give, for each type of radiation considered, the number of atoms, η, having the background intensity. It will be assumed that the atoms have been bombarded to saturation in a flux of 10^{10} per cm^2 per sec with an activation cross section of one barn. This, then, allows one to calculate the smallest number of atoms, δ, detectable in any given case. δ is given by:

$$\delta = 10^{10} \eta / \sigma_p f$$

When the material is not bombarded to saturation, δ is larger, and the exponential time factors must be included.*

β^--radiation. Without introducing a substance inside a counter, a β^--emitting material can be detected readily with either a Geiger counter or an ionization chamber. The counter is the more sensitive of these two instruments, but if moderate sensitivity only is required, an integrating type ionization chamber will be found to be more convenient. For the Geiger counter, a background of ~20 counts per minute is typical, while with an integrating and amplifying ionization chamber with a one-second time constant, a background potential of 0.3 mv is typical.

On bombarding 0.75 mg of aluminum ($\sigma_p = 0.22$ barn) to saturation ($T = 3.32$ min) in a pile flux of 10^{11} per cm^2 per sec, an extrapolated initial β^- counting rate of 1.5×10^5 per sec in a Geiger counter (solid angle $\sim \pi$) or a potential of 3.0 v in an ionization chamber (solid angle $\sim 2\pi$) will be observed. This yields the following quantities for η:

$$\eta(\beta^-\text{—G-M counter}) = 7 \times 10^{-11}$$
$$\eta(\beta^-\text{—ion chamber}) = 4 \times 10^{-9}$$

e^--radiation. Electron radiation, as distinguished from β^- radiation, results from the energy conversion of a would-

* From δ, one may calculate the smallest detectable mass, μ (given in micrograms) via $\mu = (10^6 A/0.6025)\delta$, where A is the atomic weight of the element.

be γ-ray. In general, this conversion is not complete so that only part of the activation results in e^- emission. However, it is not important to know the so-called conversion coefficient when making analyses, since the detecting instrument is calibrated with a known amount of the substance to be detected.

Conversion electrons are very conveniently detected in a no-window air ionization chamber because they are of low energy, for the most part, and will not penetrate the usual Geiger counter window. In determining η for this type of radiation, niobium can be chosen for bombardment since the conversion coefficient is $\sim$100% for this substance. On bombarding to saturation ($T = 9.5$ min) 2.6 mg of niobium oxide, and on measuring it in such an ionization chamber, a potential of 5.7 v will be observed. This yields the following quantity for η:

$$\eta(e^-\text{—ion chamber}) = 6 \times 10^{-8}$$

Both η (ion chamber) values (i.e., for β^- and e^-) are rather strongly energy dependent; η varies in some inverse manner with the energy of the electron. For example, in the two cases considered, if the η values are multiplied by the electron energy (3.1 Mev and $\sim$0.045 Mev for β^- and e^-, respectively), one finds:

$$3.1 \times \eta(3.1 \text{ Mev } \beta^-) \simeq 2 \times 10^{-8} >$$
$$0.045 \times \eta(0.045 \text{ Mev } e^-) \simeq 3 \times 10^{-9}$$

This illustrates the necessity of always calibrating the detecting instrument with a known quantity of the material to be detected. The η values merely serve to indicate beforehand the approximate limit of detection.

β^+-radiation. If only β^+ radiation is present, it may, of course, be detected in exactly the same manner as β^- radiation. It may be important, however, to separate the β^+ from possible β^- radiation. This can be done effectively with strong permanent magnets (Fig. 1).

By such simple means, the β^+ particles from copper (18.5 hr, 1.95 barns) can be detected with a Geiger counter. When 21 mg of copper are bombarded for 1 min in a flux 10^{11}, an initial counting rate of 27.6 counts per sec will be observed. Here, however, the background counting rate is $\sim$3.5 counts per sec, since considerable improper radiation is scattered into the counter. This, then, yields a value for η of:

$$\eta(\beta^+ \text{ with } \beta^- \text{ present}) = 5 \times 10^{-8}$$

γ-radiation. Gamma rays are easily detected in the presence of β^- and e^- radiation by the method of first absorbing the charged radiation in a thick beryllium or aluminum plate and then counting the γ-rays with a scintillation counter. If undesirable positron radiation is also present (not in the material to be detected), this method may not be suitable.

With a typical anthracene counter, the γ radiation from aluminum may be measured and a counting rate of $\sim 10^4$ per sec observed. The scintillation counter has a background rate of $\sim$0.05 counts per sec operating at room temperature with a 5819 photomultiplier tube having a one-electron sensitivity. This yields a value for η as follows:

$$\eta(\gamma) \simeq 2 \times 10^{-10}$$

X-radiation. As distinguished from γ-radiation, X-radiation results from the filling in of an orbital atomic electron. This process succeeds either the conversion process mentioned previously, or K-capture. In the first case, the X-ray is characteristic of the element being detected, Z. In the second case, it is characteristic of the element $Z - 1$. The method of detection most easily employed here is the same as that used for γ-rays.

The X-ray intensity is again dependent on the conversion coefficient or the fraction of K-capture. This sort of complication is usually present. In the γ-ray case, for example, the aver-

age number of γ-rays per decay must be known to evaluate η properly. This presents no difficulty, since the detector is first calibrated with a known amount of the material to be measured.

So-called "critical absorbers" may be used to advantage to emphasize X-radiation in the presence of γ-radiation. The critical absorber of K X-rays characteristic of element Z is usually the element $Z-2$ or $Z-3$. An absorber that is critical just for a given X-ray has $\sim$3 to 10 times the absorption coefficient as an element that is noncritical (usually $Z-1$). Both critical and noncritical absorbers, however, have about the same high transmission for γ-rays. Thus the difference intensity for matched (equal thickness) critical and non-critical absorbers will be essentially X-ray intensity.

Both scintillation counters and Geiger counters have rapidly varying efficiencies for X-rays as a function of energy. In general, the efficiency can be assumed higher for X-rays. However, when critical-absorber differences, the conversion coefficients, and higher backgrounds are taken into account, the η value will be about the same as for γ-rays.

Neutron Absorption and Scattering

Other methods of chemical identification include beam attenuation measurement, thermal-neutron absorption, and resonance self-indication.

Beam transmission measurements. The presence of a small quantity of some substances having a large neutron absorption or scattering cross section can be detected by its attenuation of a neutron beam. Well-collimated high-flux neutron beams are easily obtained from a pile.

The method of measurement is indicated in Fig. 2. A collimated neutron beam from the pile passes through the sample being measured and then into a BF_3-filled proportional neutron counter. Counting rates are taken with and without the sample in the beam.

For example, let us consider a two-component sample in which the material to be detected is present to the extent of n_1 atoms per cm^2 (units of 10^{24}) with cross section σ_1 (barns). Suppose the rest of the material is present to the extent of n_2 atoms per cm^2 with cross section σ_2. Then if I_0 is the intensity without the sample in the beam, I is the intensity with the sample in the beam, and I_B is the background intensity:

$$I - I_B = (I_0 - I_B)e^{-n_1\sigma_1 - n_2\sigma_2}$$

from which:

$$n_1\sigma_1 + n_2\sigma_2 = \ln \frac{I_0 - I_B}{I - I_B}$$

From the mass per cm^2, m, of the sample:

$$m = (n_1A_1 + n_2A_2)/N$$

where A_1 and A_2 are the respective atomic weights and N is Avogadro's number (units of 10^{24} atoms). Then:

$$n_1 = \left(\ln \frac{I_0 - I_B}{I - I_B} - \frac{mN\sigma_2}{A_2}\right) \Big/ \left(\sigma_1 - \frac{A_1}{A_2}\sigma_2\right)$$

The greatest accuracy obtainable in a transmission measurement is for an attenuation of $\sim$50%, and this can be measured to $\sim$1%. The most sensible means of expressing the limit, in this case, is by the smallest fraction n_1/n_2 that can be detected.

$$n_1\sigma_1 \sim 0.02 \qquad n_2\sigma_2 \sim 0.7$$

$$\therefore \left(\frac{n_1}{n_2}\right)_{\min} \approx 0.028\,\frac{\sigma_2}{\sigma_1}$$

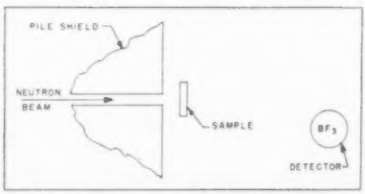

FIG. 2. Collimated beam of neutrons passes through sample into BF_3 proportional counter

Thermal-neutron absorption. The preceding discussion applies to the case of a large thermal-neutron absorption or scattering cross section. The pile beam contains not only thermal neutrons but faster neutrons as well (resonance neutrons). If counting rates are taken, with and without cadmium in the beam, the thermal transmission may be isolated. This is so because cadmium absorbs thermal neutrons exclusively. The thermal transmission, however, should be calibrated with a known quantity of the substance being detected.

A practical problem to illustrate this is the determination of lithium content in a 5% lithium-magnesium alloy (i.e., in which the Li fraction is ~5% atomwise). A careful wet chemical analysis of this material would take several days. By the pile neutron method, only a half hour is needed. In this case:

$$\sigma_1 = \sigma_{(Li)} = 66.5 \text{ barns}$$

$$\sigma_2 = \sigma_{(Mg)} = 3.66 \text{ barns}$$

$$\left(\frac{n_1}{n_2}\right)_{min} \simeq 0.028 \frac{3.66}{66.5} \simeq 2 \times 10^{-3}$$

Since the actual atom ratio measured is 0.05, the percent lithium could be measured to ~0.2%. That is:

$$\% \text{ Li} = 5.0 \pm 0.2\%$$

Resonance self-indication. Many elements possess large neutron absorption or scattering resonances in the energy range from 1 ev to 5,000 ev. Detection of these elements by resonance self-indication is both a sensitive and a practical means of chemical identification.

A resonance cross section, σ_r, as a function of energy, E, is given by the Breit-Wigner formula:

$$\sigma_r = \frac{\sigma_0}{\left(\frac{E - E_0}{\Gamma/2}\right)^2 + 1}$$

$$\sigma_0 \sim \frac{1.3 \times 10^6}{E_0} \text{ (for } E_0 > 50 \text{ ev)}$$

where σ_0 is the peak cross section, E_0 the resonance energy, and Γ the width of the resonance at half maximum.

When a beam of resonance neutrons (epi-thermal or Cd filtered) from the pile is allowed to irradiate a thin foil of some material having a strong neutron resonance, the neutrons are selectively scattered or absorbed near the resonance energy. This is termed "resonance detection." If a second thin foil of the same material is placed in the neutron beam, a high transmission cross section is indicated. That is, the neutrons that are strongly selected

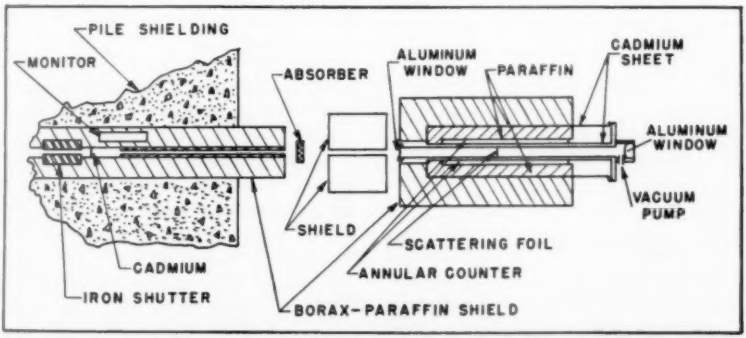

FIG. 3. Setup used to count scattered neutrons. Collimated beam of resonance neutrons from heavy-water reactor passes through evacuated tube surrounded by annular BF_3 proportional counter. Scattering foil is placed in central tube traverse to neutron beam

by the first foil are selectively removed from the beam by the second foil.

It can be shown that the transmission cross section indicated by this self-absorption procedure is $\sim\sigma_0/2$. Since $\sigma_0/2$ is large ($\sim$5000 barns for E_0 $\sim$100 ev), a very small amount of material suffices to give a strong self-indication

The method of self-indication can be applied to cases in which either absorption or scattering is predominant. Since the principle is the same in both, only the scattering case will be discussed here.

Fig. 3 illustrates a scattering setup that can be used. A collimated beam of resonance neutrons from the heavy-water reactor passes through an evacuated tube that is surrounded by an annular BF_3 proportional neutron counter. This, in turn, is surrounded by a paraffin reflector and shield. Scattered neutrons are counted when a scattering foil is placed in the central tube transverse to the neutron beam. Using the transmission analysis:

$$\left(\frac{n_1}{n_2}\right)_{\min} \simeq 0.028\,\frac{\sigma_2}{\sigma_0/2} \simeq 0.05\,\frac{\sigma_2}{\sigma_0}$$

where n_1/n_2 is again the smallest fraction of resonance substance one that can be detected in substance two.

Let us now examine a practical case in which 0.1% manganese is alloyed with rhenium. Here $\sigma_0 = \sigma_0(\mathrm{Mn}) \simeq$ 4,400 barns, and $\sigma_2 = \sigma_{\mathrm{scatt}}(\mathrm{Re}) = 15.0$ barns.

$$\left(\frac{n_1}{n_2}\right)_{\min} \simeq 0.05\,\frac{15.0}{4{,}440}$$

$$\simeq 2 \times 10^{-4} = 0.02\%$$

$$\therefore\ \%\ \mathrm{Mn} = 0.10 \pm 0.02\%$$

Photoneutrons from Beryllium or Deuterium

Rarely is the presence of a γ-ray (resulting from neutron activation) sufficiently energetic to disintegrate (γ,n) Be (1.63 Mev) or D (2.2 Mev). This offers a means of detection which is completely unperturbed by the presence

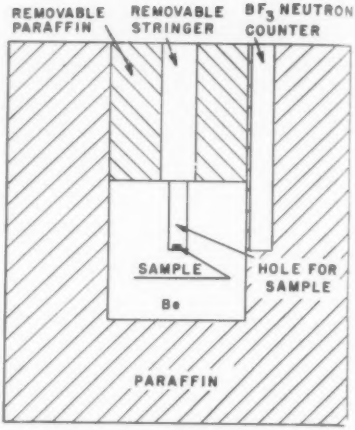

FIG. 4. Schematic representation of apparatus for measuring photoneutrons produced by beryllium

of softer γ-rays (i.e., from the bulk material).

Fig. 4 illustrates schematically a method for measuring photoneutrons from 9.03 kg beryllium. Calibration of the apparatus can be effected by bombarding 0.47 gm of aluminum (E = 1.8 Mev) to saturation (T = 3.32 min) in a neutron flux of 10^{11} per cm^2 per sec. The initial neutron counting rate observed from the Al γ-rays on Be is 2,600 per sec with a background of 0.15 counts per sec. This yields an η value of:

$$\eta(\mathrm{Al}) = 1.4 \times 10^{-6}$$

η, of course, depends on the photoneutron cross section as a function of γ-ray energy.

Again it is necessary to calibrate the apparatus for any given case. When 5.9 mg of manganese (T = 3.74 hr) are bombarded 2 hr in a flux of 10^{11} per cm^2 per sec, an initial neutron counting rate of 130 counts per sec is observed. This yields an η value of:

$$\eta\ (\mathrm{Mn}) = 3.8 \times 10^{-6}$$

η (Al) $\neq \eta$ (Mn) not only because the γ-ray energies are different, but because 3.74-hr Mn has only $\sim$50% hard

(2.1 and 1.8 Mev) γ-rays per decay. Correcting for this yields:

$$\eta(1.8 \text{ Mev}) = 1.4 \times 10^{-6}$$
$$\eta(\sim 1.9 \text{ Mev}) = 1.9 \times 10^{-6}$$

These numbers should be in the inverse ratio of the photoneutron cross sections.

Let us consider once again the case of 0.1% of manganese in 10 gm rhenium. Neutron-activated rhenium (T_1 = 29.3 hr, T_2 = 133 hr) has no reported γ-rays with energy > 1.63 Mev.* Therefore, the smallest amount of manganese, δ, that can be detected in this arrangement by use of a flux of 10^{10} per cm^2 per sec is:

$$\delta \simeq 3 \times 10^{-7}$$

or $$\% \text{ Mn} = 0.10 \pm 0.001\%.$$

It should be noted that this method is 20 times more sensitive than self-indication (for 10 gm Re and 10^{10} flux).

Counting During Irradiation

When slow-neutron absorption gives rise to instantaneous charged-particle emission (n,p; n,d; n,f; etc.), very sensitive methods of detection are possible. The absorbing material is placed inside a proportional counter which is irradiated with a flux of slow neutrons. Very small amounts of material ($\sim 10^{10}$ atoms) may be detected in this way, but the smallest detectable fraction (when mixed with an inert material) is limited by the range of the emission particle in the bulk (i.e., inert) material. For example, if the emission particle loses its kinetic energy after passing through 10^4 atoms, then: $\left(\frac{n_1}{n_2}\right)_{\min} \simeq 10^{-4}$ or 0.01%

Capture γ-rays, which are usually emitted at the instant of neutron capture (n,γ), and average approximately 3 per capture, may also be used for detection of strong thermal-neutron absorbers. All such methods, however, are rather special and will not be dealt with further in this paper.

TABLE OF NEUTRON PROPERTIES

The columns in the table of neutron properties on pages 16 and 17, instead of containing elements with like chemical properties (i.e., valence), contain elements with like neutron-nuclear properties. Any one element, therefore, may appear in several columns. An element that has a very outstanding property is indicated by boldface type.

In addition to the properties already discussed, auxiliary ones are listed to aid the analyst in deciding on the best means of differentiating between two elements (i.e., the one to be detected and the bulk material).

The column termed *Natural Activity* is self-explanatory. The pile is usually needed for these materials since the natural activity is weak.

Coincidence counting (β-γ, γ-γ, etc.) is considered too special a technique to be included in this paper. However, one rare (and, consequently, highly characteristic) type of β-γ coincidence is that in which the γ-ray is delayed by a time $\sim 10^{-7}$ sec with respect to the β^--ray. A β-γ coincidence can then be observed only if the β^--count (e.g., in a Geiger counter) is electronically delayed by a time $\sim 10^{-7}$ sec. This method has been used at Oak Ridge to analyze for Hf in Zr via the 20-microsecond state in Ta^{181}.

The column termed *No Gamma Ray* means that, on neutron activation, no γ-ray is present in the decay scheme. This is a very useful property of a bulk material in which a small quantity of some γ-active substance to be detected has been mixed.

Another column of importance is the one termed *Cadmium Ratio.* In this column are listed elements whose activities have very large or very small cadmium-ratios (ratio of activity without cadmium cover to activity with

* The performance of this experiment at Argonne National Laboratory revealed the presence of a γ-ray in Re^{188} with energy > 1.63 Mev but < 2.2 Mev which accompanied one in ~750 Re^{188} disintegrations.

TABULATION OF

Neutron Property	β^-	e^-	β^+	γ	X
Type of Detection	G or I	I	G	S	S
η or $\left(\frac{n_1}{n_2}\right)_{min}$	$\sim 7 \times 10^{-11}$ or $\sim 4 \times 10^{-3}$	$\sim 6 \times 10^{-6}$	$\sim 5 \times 10^{-6}$	$\sim 2 \times 10^{-10}$	

NOTE: Elements with outstanding neutron-nuclear properties are shown in boldface type.

G—Geiger Counter
I—Ionization Chamber
B—Boron Counter
S—Scintillation Counter

β^-			e^-	β^+	γ		
Li	As	Ce	**Sc**	Fe	O	Cd	Cr
O	Se	Pr	Cr	Cu	F	In	Fe
F	Br	Nd	Co	Zn	Na	Sn	Co
Na	Kr	Sm	Zn	Ge	Mg	Sb	Cu
Mg	Sr	**Eu**	Se		Al	Te	Zn
Al	Y	Gd	Br		Cl	I	Se
Si	Zr	Tb	Kr		A	Xe	Br
P	Mo	**Dy**	Sr		Ca	Cs	Kr
S	Ru	Ho	Nb		Sc	Ba	Sr
Cl	Rh	Er	Rh		Ti	La	Nb
A	Pd	Tm	Cd		V	Ce	Ru
Ca	**Ag**	Yb	In		Cr	Pr	Rh
Sc	Cd	Hf	Sb		Mn	Sn	Cd
Ti	**In**	Ta	Te		Fe	Eu	In
V	Sn	W	Cs		Co	Gd	Sb
Mn	Sb	Os	Ba		Ni	Tb	Te
Fe	Te	Ir	Sm		Cu	Dy	Cs
Co	I	Pt	**Dy**		Zn	Ho	Ba
Ni	Xe	Au	Ho		Ga	Er	Sm
Cu	Cs	Hg	**Hf**		Ge	Tm	Eu
Zn	Ba	Tl	W		As	Yb	Dy
Ga	La	Pb	Os		Se	Hf	Ho
Ge		Bi	**Ir**		Br	Ta	Hf
			Pt		Kr	W	W
			Hg		Sr	Os	Os
			Pb		Zr	Ir	Ir
					Mo	Pt	Pt
					Ru	Au	Hg
					Rh	Hg	Pb
					As	Pb	

cadmium cover). An additional aid in differentiation is obtained by bombarding with or without cadmium, i.e., with resonance or resonance-plus-thermal neutrons.

Under the heading *Fast Neutrons* are listed a number of elements possessing sizable (~ 0.1 barn) activation cross sections for neutrons of about 1-Mev energy. Fast neutron bombardment, then, sometimes affords a means of distinguishing between two elements which have too similar a set of slow neutron properties.

In addition to all the qualitative properties so far mentioned, there is,

NEUTRON PROPERTIES

Thermal Trans.	*Resonance Trans.*		*Photo-neutron*	*Natural Activity*	*Delayed Coincidence*	*No Gamma Ray*	*Cadmium Ratio*		*Fast Neutron*
	Scatt.	*Abs.*					*Large*	*Small*	
B	Self		B	G or S	G & S				
$\sim 0.028\sigma_2/\sigma_1$			$\sim 1.5 \times 10^{-6}$						
H	Eu	Sc	Rh	Na	K	Ga	H	Na	Br	P
Li	**Gd**	**V**	Ag	Al	Rb	Er	Li	Mg	Ag	Ag
B	Tb	Mn	In	Cl	Nd	Hf	Be	Al	In	In
N	Dy	**Co**	Ta	Mn	Sm	W	C	Si	**Sb**	Sb
Cl	Ho	Cu	Ir	Ga	Lu	Au	N	P	I	I
Sc	Tm	Zn	Au	As	Re		Si	S	Hf	W
Co	Hf	Ga		**Sb**			P	Cl	Ta	Au
Rh	Ta	Ge		La			S	A	W	Hg
Ag	W	As		Re			V	Ca	Ir	
Cd	Re	**Sm**					Pd	Sc	Au	
In	In	Hf					Tl	V		
Cs	Ir	**W**					Bi	Dy		
Nd	Au	Tl								
Sm	Hg									

of course, the quantitative aspect of lifetime. Often two elements will have very similar neutron-activated radiations, but will differ considerably in mean life. This will then allow the analyst to distinguish between the two substances. The same consideration applies to the energy of the radiation. Information on mean life and radiation energy can be found in a table of radioactive isotopes, but is too extensive to be included here.

Application of Table and Method

The table of nuclear properties given here is not a cookbook of recipes for making analyses. It, in conjunction with a table of radioactive isotopes, can serve to guide the analyst only in selecting the most sensitive means of differentiating between two given elements. The best method for emphasizing a given element in the presence of another still requires careful judgment. It is hoped that the table will serve to indicate to the analyst the proper procedure.

The nuclear methods described are only generally applicable to a two-component system. In most cases the methods of wet chemical or spectroscopic analysis are still necessary for a many-component system. The table was not designed for the analysis of "dirt." The analyst should know in advance what elements (preferably two) are present. They should offer difficulty to analysis by ordinary means, i.e., for reasons of sensitivity or labor. Nuclear analysis profitably replaces ordinary chemical analysis when either

(Continued on page 59)

Distributed Beta Sources in Uniformly Absorbing Media—I*

Values of dose and flux may be estimated if a beta-emitting isotope is uniformly distributed in a limited region of a biological medium, and if such a "distributed source" has one of a number of simple geometric shapes. In this introduction to the subject, theoretical considerations are noted

By HARALD H. ROSSI and R. HOBART ELLIS, Jr.

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A KNOWLEDGE of the beta flux or the dose from extended sources of beta-emitting substances is of fundamental importance in physical and biological research involving radioactive materials. While these quantities may usually be determined experimentally, it would often be preferable to predict them, even if such a prediction should be in error by 10 or 20%.

If, for instance, one wishes to know the dose throughout an amphibian egg floating in a solution of radioactive phosphorus, theoretical values having a possible error of 20% or perhaps even more may be more desirable than the prospect of a rather difficult experimental investigation.

Unfortunately, the computation of dose is usually difficult also. The only case in which an extended source may be treated simply and rigorously is the one in which a beta-emitting isotope is uniformly distributed throughout a medium. Then at points of radiation equilibrium (i.e., regions inside the source which are removed from the surface by distances equal to or exceeding the maximum beta range), the energy imparted per unit volume is given by the product of the number of particles emitted per unit volume, C,† and the average energy carried per particle, E.

This result follows immediately from the law of conservation of energy which may be interpreted to the effect that the total energy emitted per unit volume equals the total energy absorbed per unit volume. Near the boundary of an extended source, the energy emitted is unequal to the energy absorbed and the above reasoning may no longer be applied.

Thus if the "infinite" medium under discussion is divided by an infinite plane, two regions will result which will be called "half spaces." If the activity contained in one of these half spaces is removed, the resulting geometry is an active half space bordering an inactive half space. The dose in this

* This article is based on work performed under Contract AT-30-1-GEN 70 for the Atomic Energy Commission.

EDITOR'S NOTE: Part II, the concluding portion of this article to be published next month, is devoted to practical applications of this method.

† C is defined *not* as the *rate* of emission (e.g., millicuries) but as the total number of particles emitted (e.g., millicurie seconds). This definition eliminates the time element and yields results in terms of dose rather than dose rate.

configuration will vary from CE in regions of the active half space that are far from the dividing plane to zero in those regions in the inactive half space that, also, are far from the common surface. No immediate information can be given on the variation of dose with distance except that, for reasons of symmetry, the dose at the dividing plane must be $CE/2$.

In any but the instances mentioned above, dose can be calculated only if an appropriate analytical function expressing beta absorption is known and if this function is integrated over the geometrical configuration under consideration. This is a difficult task since, as will be seen, even a simple approximation to the absorption function and the elementary geometry of a half space lead, at all points except the surface, to an expression which cannot be integrated in finite terms. Nevertheless the integral in question is tabulated and the values required can be computed.

In addition to the half space, plane sources, infinite slabs, and spheres are treated in detail in the following paragraphs. An exponential absorption law is assumed, and it will be seen that this approximation may be expected to give rather accurate results in certain cases which are of practical importance.

It should nevertheless be stressed that the primary purpose of this work is to supply approximate rather than precise information and that the calculations to be presented are bound to deviate from reality. Their usefulness will depend on the degree of accuracy sought and on the specific problem under consideration.

Absorption of Beta Rays

The mathematical complexity of the required integrations makes it imperative that a simple mathematical function be chosen to represent average absorption of the entire beta spectrum.

It is commonly agreed that the best function for the purpose is a simple exponential and that this approximation is useful for both number of particles (as measured by a counter) and ionization (as measured by an ionization chamber) at distances which are not too large a fraction of the average beta range.* Eventually, of course, the exponential, which implies an infinite range, leads to values larger than the actual values obtained, which go to zero at the maximum beta range. However, as will be seen, in many practical cases the regions of discrepancy are of little interest because the dose has reached values which are small compared to the maximum dose present in the configuration.

It will be assumed that the source and the surrounding medium are of essentially the same atomic composition and density, i.e., that the absorption and scattering coefficients for betas are constant throughout the volumes under consideration.

Since absorption is strictly exponential for gamma rays, the approximation employed here leads to the same mathematical treatment. There is a rather extensive literature on theoretical gamma dosimetry. However, in most cases the absorption term has been neglected since its effect is usually small. Where allowance has been made for absorption,†‡ the treatment has been somewhat limited or approximate.

As pointed out by Sievert§ and then elaborated by Mayneord,† there exists a reciprocal relationship between sources and absorbers. For a uniform

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* G. Friedlander, J. Kennedy, "Introduction to Radiochemistry," p. 158 (John Wiley & Sons, Inc., New York, 1949).

† W. Mayneord, *British J. Radiol.* **18**, 12 (1945)

‡ L. D. Marinelli, E. Quimby, and G. J. Hine, *Am. J. Roentgenol. Radium Therapy* **59**, 260 (1948); also NUCLEONICS **2**, No. 4, 56, and No. 5, 44 (1948).

§ R. Sievert, *Acta Radiol.* **6**, 268 (1923)

medium this may be expressed as follows: The integral dose received by any volume, A, from a point source, P, of activity, C, is equal to the dose received at P if A is uniformly filled with the same radiating material of concentration C per unit volume. Since the computations to be presented give doses from extended sources at various points, they may also be used to obtain the integral doses from point sources.

The usefulness of the following computations will, of course, depend on the availability of reliable values of the linear absorption coefficient for beta spectra of various maximum energies. Siri* compiled data from several observers, and the spread of the values is considerable.

It is quite difficult to perform a measurement of the true linear absorption coefficient of betas in which the particles scattered out of the beam are compensated for by particles scattered into the beam, and in which an equal distance in the absorber is traversed by any straight line between a point of the source and a point of the detector. Thus it seems likely that most of the values quoted in the table do not represent a true absorption coefficient in this particular meaning but merely refer to an attenuation observed with a particular experimental arrangement.

In experiments performed at this laboratory, the depth dose from "thick" sources of beta emitters was determined. It is possible to fit a theoretical curve obtained from the following computations to these experimental results and to obtain in the process a linear absorption coefficient which is presumably an average for a considerable portion of the range.

* W. Siri, "Isotopic Tracers and Nuclear Radiations with Applications to Biology and Medicine," p. 72 (McGraw-Hill Book Co., Inc., New York, 1949). (In addition to the variations discussed, most of these data seem to be in error by a factor of 10^3, because the heading chosen for the columns should be cm^2/gm rather than cm^2/mg.)

Different geometries may require somewhat different average absorption coefficients, but in the absence of further information it will be necessary to use these values for all geometries treated in the following discussion.

Dose from a Point Source

The dose, K, from a point source emitting radiation of total energy CE, which is absorbed exponentially with an absorption coefficient μ, takes the form

$$K(R) = (\sigma/R^2)e^{-\mu R} \qquad (1)$$

The value of σ may be computed from the requirement that

$$\int_{R=0}^{R=\infty} K\,dv = CE \qquad (2)$$

i.e., that the total energy absorbed is equal to the total energy emitted. Substitution of Eq. 1 into 2 and integration yields

$$\sigma = (CE\mu / 4\pi) \qquad (3)$$

Thus

$$K(R) = (CE\mu/4\pi R^2)e^{-\mu R} \qquad (4)$$

The dose from a differential volume dv in a medium containing a beta emitter at a concentration C per unit volume will be $K(R)\,dv$.

Dose from a Half Space

Consider a point P at a distance H from the boundary of the half space containing a concentration C of the beta emitter. Referring to Fig. 1, it

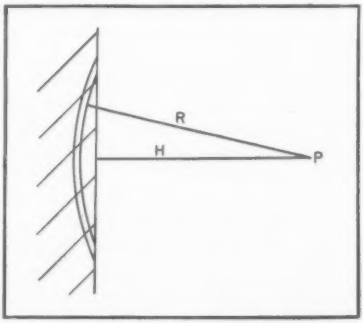

FIG. 1. Geometry for dose from a half space

will be seen that the dose from a spherical shell of radius R is given by

$$dM = \frac{CE\mu}{4\pi R^2} e^{-\mu R} \times 2\pi R(R - H)\, dR \tag{5}$$

the second factor being the volume of the differential shell. Integration yields

$$m_\infty(H) = \frac{M_\infty(H)}{CE} = \frac{\mu}{2}\left[\int_H^\infty e^{-\mu R}\, dR - H\int_H^\infty \frac{e^{-\mu R}}{R}\, dR\right] \tag{6}$$

Expressing all distances in multiples of $1/\mu$,

$$R = \frac{r}{\mu} \qquad H = \frac{h}{\mu} \tag{7}$$

$$m_\infty(h) = \frac{1}{2}\left[\int_h^\infty e^{-r}\, dr - h\int_h^\infty \frac{e^{-r}\, dr}{r}\right] \tag{8}$$

The second expression cannot be integrated in finite terms but has been tabulated extensively* as the exponential integral $-E_i(-h)$. Thus

$$m_\infty(h) = \tfrac{1}{2}[e^{-h} + hE_i(-h)], \qquad h > 0 \tag{9}$$

This relation is plotted as a solid line in Fig. 2.

The fractional dose inside the active half space must be given by

$$m_\infty(-h) = 1 - m_\infty(h) \tag{10}$$

because it may be considered as the difference between the contribution of an infinite active space and the contribution of an active half space in the position of the inactive half space.

Experiments performed at this laboratory by N. A. Baily† make it possible to check Eq. 9.

Uniform thick sources were produced by molding mixtures of beta emitters and powdered polystyrene. The dose at the surface was measured by extrapolation. Depth doses were measured by the same technique after various thicknesses of inactive polystyrene sheet were placed over the beta source.

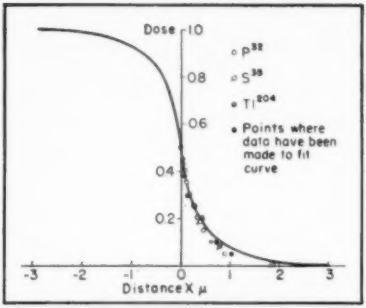

FIG. 2. Theoretical dose at various distances from the surface of an infinite half space. Points superimposed are from unpublished data of Baily

To compare these measurements with Eq. 9, the experimental and theoretical curves were made to coincide at values of 0.5 and 0.25 for m_∞. The choice of the second point is arbitrary, but fitting the curves at another value will change the apparent discrepancy very little. In Fig. 2 it will be seen that the theoretical curve begins to diverge around $m_\infty = 0.1$. The disagreement seems to be most serious for P^{32}. This may be caused by the high energy of the beta ray which makes for a shorter linear portion in an exponential absorption plot as determined with a counter.‡

The values for μ obtained from this comparison are:

Isotope	*Absorption Coefficient, μ*
S^{35}	0.192 cm²/mg
Tl^{204}	0.019 "
P^{32}	0.004 "

To obtain some information on μ for other isotopes, these values were used in the plot of Fig. 3. Instead of μ, its reciprocal (the thickness of the $1/e$ layer) was plotted, since this procedure yielded an additional point ($1/\mu = 0$ for $E_{max} = 0$) rather than an asymptote ($\mu = \infty$ for $E_{max} = 0$); this makes for a better defined curve.

* "Tables of Sine, Cosine and Exponential Integrals" (Federal Works Agency, WPA, for the City of New York 1940).

† To be published.

‡ L. E. Glendenin, NUCLEONICS **2**, No. 1 12 (1948).

Dose from an Infinite Slab

The dose $m_t(h)$ at a distance $H = h/\mu$ from an infinite layer of thickness $T = t/\mu$ may be obtained by subtracting from the dose from a half space at a distance h/μ the dose from a half space at a distance $(h + t)/\mu$. That is,

$$m_t(h) = m_\infty(h) - m_\infty(h + t) \quad (11)$$

Similarly the dose inside such a slab at a distance h/μ from its surface will be given by subtracting from the dose at a distance h/μ into a half space the dose which is found at a distance $(t - h)/\mu$ from a half space:

$$m_t(-h) = m_\infty(-h) - m_\infty(t - h) \quad (12)$$

These values can be readily obtained from the curve in Fig. 2 and have been plotted in Fig. 4.

It should be pointed out that the error to be expected if these curves are applied in practice will vary somewhat depending on the value of t chosen. For $t = 1$ and $h = 0$, the absolute error will be equal to the difference between theoretical and experimental values of $m_\infty(1)$ (Fig. 2). For lower values of t, obtained by subtraction of m_∞ values which are larger, the absolute error will be smaller because the number subtracted from $0.5\,[m_\infty(0)]$ is known to be more accurate. In view of the nature of the m_∞ curve it would appear that the percentage error involved would be smaller also. However a certain error must be present even in the case of the thinnest sheet since the integration still is carried to infinity rather than to a finite range.

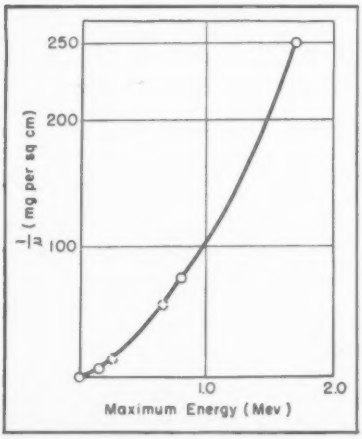

FIG. 3. $1/\mu$ as a function of E_{max}. Full circles are experimental values for S^{35}, Tl^{204}, and P^{32} (Baily). Dotted circles are values assumed for the two I^{131} β-spectra

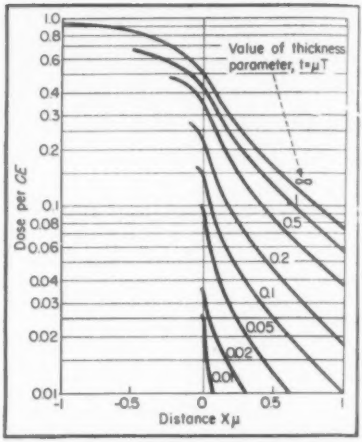

FIG. 4. Fractional dose as a function of distance from the surface of infinite slabs having various thicknesses and constant activity per unit volume

Thin Plane Source

If an infinite, flat, two-dimensional source is surrounded by a uniform medium, the differential element of emitting surface may be written as $2\pi\rho d\rho$ (Fig. 5). Since $R^2 = \rho^2 + H^2$, $\rho d\rho$ is equal to RdR. Thus the element of dose, dM_0, is equal to

$$dM_0 = \frac{DE\mu}{4\pi R^2} e^{-\mu R}\, 2\pi R dR \quad (13)$$

where D is the activity per unit surface area. Thus

$$m_0(h) = \frac{\mu}{2}\int_H^\infty \frac{e^{-\mu R}}{R}\, dR = \frac{\mu}{2}\int_h^\infty \frac{e^{-r}}{r}\, dr$$

$$= \frac{\mu}{2}\,[-E_i(-h)] \quad (14)$$

For a disk of radius $L = \lambda/\mu$,

$$_{\lambda}m_0(h) = \frac{\mu}{2}\left[-E_i(-h) - E_i(-\sqrt{\lambda^2 + h^2})\right] \quad (15)$$

Particle Flux Above Plane Sources and Slabs

Assuming that the same absorption coefficient may be applied to obtain both the dose from a beta source and the actual number of betas as a function of distance, it is clear that the density of betas in any of the previous configurations may be obtained simply by dividing the values of M by μE. This comes about because the density of betas from a point source must be given by $\mu(C/4\pi R^2)e^{-\mu R}$ if the exponential law is used as an approximation.

The density of betas so obtained is of little practical value since, in experimental work, individual particles are usually measured with an end-window counter that measures the number of betas crossing a plane surface, which is substantially the area of the window.

To obtain the flux, Φ, above a two-dimensional source, the solid angle, subtended by an area dA as seen from a differential element of the source at a distance R, must be written as $dA \cos \alpha$ (Fig. 6). Division of Eq. 13 by μE, shows that the differential element of the source contributes a beta density:

$$\frac{dM_0}{\mu E} = \frac{D}{2R}e^{-\mu R}\,dR \quad (16)$$

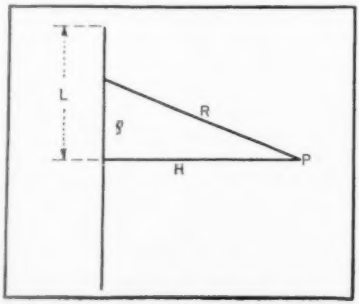

FIG. 5. Geometry for the dose from a plane source

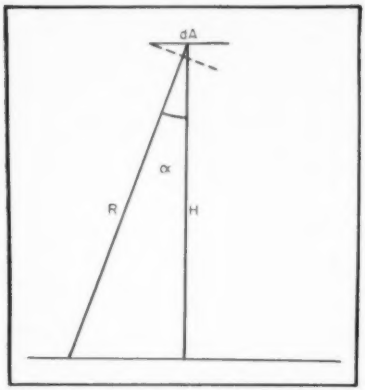

FIG. 6. Geometry for the count from a plane source

Since $\cos \alpha = H/R$, the differential element of flux, $d\Phi_0$, is

$$d\Phi_0 = \frac{DH}{2}\frac{e^{-\mu R}}{R^2}\,dR \quad (17)$$

and

$$\Phi_0(H) = \frac{DH}{2}\int_H^{\infty}\frac{e^{-\mu R}}{R^2}\,dR \quad (18)$$

This may be shown to be equivalent to

$$\Phi_0(h) = (D/2)\left[e^{-h} + hE_i(-h)\right] \quad (19)$$

This expression is the same as the one giving the dose above a half space (Eq. 9) if D is taken equal to C.

To obtain the beta flux above a half space, the cosine factor appears again:

$$\Phi_\infty(H) = \frac{C}{4\pi}\int_0^{2\pi}d\psi\int_H^{\infty}dR \int_0^{\cos^{-1}\frac{H}{R}}d\theta\, e^{-\mu R}\cos\theta\sin\theta \quad (20)$$

Substitution of Eq. 7 and integration yields

$$\Phi_\infty(h) = \frac{C}{4\mu}\left[e^{-h}(1-h) - h^2E_i(-h)\right] \quad (21)$$

Since the flux from a thick source must be the same as the flux from an infinite number of thin sources, Eq. 21 could be obtained by integration of Eq. 19 from h to ∞, with $D = C(dt/\mu)$.

Similarly the dose above a plane source (as given in Eq. 14) could be

derived by differentiation of Eq. 9.

The flux above a slab of thickness, t/μ, is obviously

$$\Phi_t(h) = \Phi_\infty(h) - \Phi_\infty(t + h) \quad (22)$$

The relationships represented by Eqs. 14, 19, 21, and 22 are plotted for constant values of D in Figs. 10 and 11 to appear in Part II.

Dose Outside a Spherical Source

Considering a point P (Fig. 7) at a distance B from the center of a spherical source of radius A, the differential volume element of the latter which is a distance R from P is given by

$$\frac{\pi R}{B}\,[A^2 - (B - R)^2]\,dR$$

Thus the dose at P will be

$$N_A(B) = \frac{\mu CE}{4B}\int_{B-A}^{B+A} \frac{A^2 - (B - R)^2}{R}\,e^{-\mu R}\,dR \quad (23)$$

Expressing all distances in multiples of $1/\mu$,

$$A = a/\mu \qquad B = b/\mu \qquad R = r/\mu \quad (24)$$

substitution in Eq. 23 and integration yields

$$n_a(b) = \frac{1}{4b}\,[(b + a - 1)e^{-(b-a)} - (b - a - 1)e^{-(b+a)}] - \frac{b^2 - a^2}{4b}\,\{-E_i[-(b - a)] + E_i[-(b + a)]\}; \quad b \gtrsim a \quad (25)$$

Dose Inside a Spherical Source

Here the differential element may be taken as $4\pi R^2\,dR$ between $R = 0$ and $R = (A - B)$, and $\pi R/B\,[A^2 - (B - R)^2]\,dR$ between $R = (A - B)$ and $R = (A + B)$. (See Fig. 8.) Thus

$$N_A(B) = \mu CE\left[\int_0^{A-B} e^{-\mu R}\,dR + \frac{1}{4B}\int_{A-B}^{A+B} \frac{A^2 - (B - R)^2}{R}\,e^{-\mu R}\,dR\right] \quad (26)$$

After substitution according to Eq. 24, this may be shown to be equivalent to

$$n_a(b) = 1 - \frac{1}{4b}\,\{(a + b + 1)e^{-(a-b)} - (a - b + 1)e^{-(a+b)}\} + \frac{a^2 - b^2}{4b}\,\{-E_i[-(a - b)] + E_i[-(a + b)]\}; \quad b \leq a \quad (27)$$

As written, this expression is indeterminate for the dose at the center of the sphere ($b = 0$), but it can be shown that it reduces to the correct value $(1 - e^{-a})$.

Doses inside as well as outside spheres of various radii are plotted in Fig. 9.

It will be seen that for the largest sphere given ($a = 5$) the dose distribution is very nearly the same as for an infinite half space. It has been shown that for the latter the inherent error (due to the approximate nature of the function chosen for beta absorption) becomes appreciable at a distance of

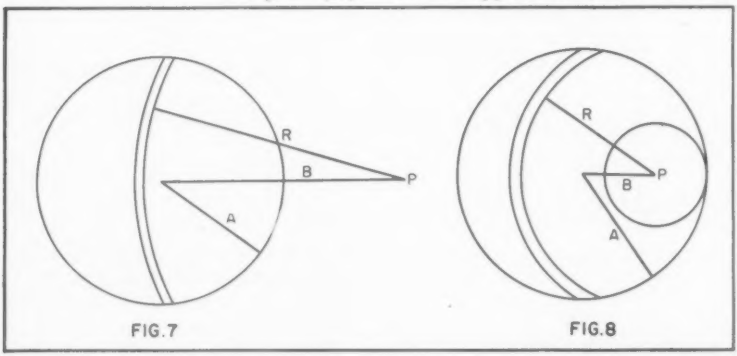

FIG.7 FIG.8

Geometry for the dose (FIG. 7) outside a sphere . . . and (FIG. 8) inside a sphere

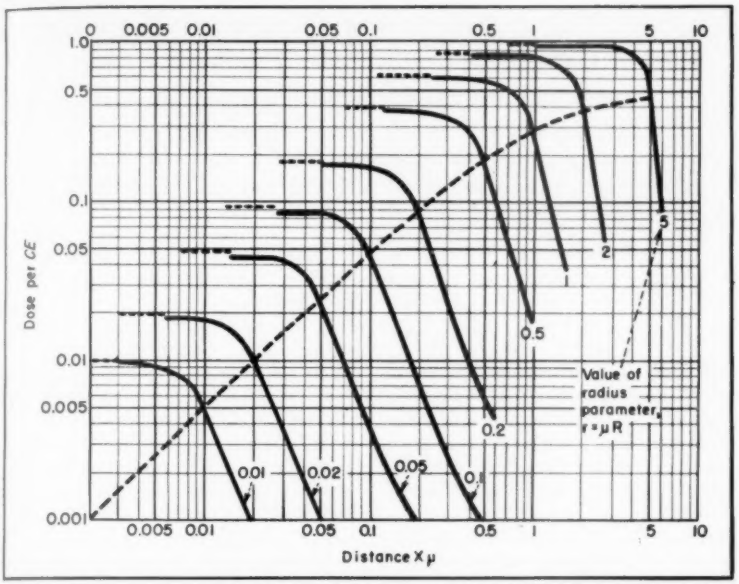

FIG. 9. Dose as a function of distance from the center for spheres having various radii and the same activity per unit volume. Dotted line at the end of each curve gives value of center dose for that sphere. Dashed line shows surface dose for the spheres

$1/\mu$ from the surface. For this reason, the curve for $a = 5$ has been shown only to this distance.

For smaller spheres, n_a may be assumed to be a good approximation for distances from the surface which are even larger, since the finite source size does not lead to integration over volumes which are infinitely far away, as in the case of the slabs. For this reason, the values in Fig. 9 may be regarded as rather accurate, especially in the case of the smaller spheres.

$[N_a(a)]/[N_a(0)]$, the ratio of the doses at the surface and at the center of a sphere, is equal to 0.5 for both large spheres (where $N_a(a) = 0.5CE$ and $N_a(0) = CE$) and small spheres (where $N_a(a) = (a/2)CE$ and $N_a(0) = aCE$). For spheres with radii comparable with $1/\mu$, the ratio turns out to be somewhat smaller. For instance, for $a = 2$, the ratio is 0.44.

This is quite different from the case of slabs where a thinning of the slab tends to make the dose throughout the structure more uniform. Thus, for a slab having $t = 0.01$, the ratio $[M_t(0)]/[M_t(-t/2)]$ is 0.96 (because most of the activity contributing to the dose is rather far from the dose measuring point).

The dose distribution due to a spherical "hole"—i.e., the case in which a spherical inactive object is in a large volume containing uniform activity—may be obtained simply by subtracting the dose from a spherical source from CE, the dose in a continuum.

The dose anywhere inside a spherical shell of activity is obviously given by $(N_{a_1} - N_{a_2})$, where a_1 and a_2 are the outside and inside radii of the shell. The dose at the center of a section of a shell must be equal to $\omega/4\pi[N_{a_1}(0) - N_{a_2}(0)]$, where ω is the solid angle subtended by the section. —END

Improved Film Badge for Personnel Monitoring

Identification of radiation of different energies, decrease in calibration time, and greater accuracy of interpreting mixed-exposure badges are obtained with this new film badge. A combination of silver filters and lead shields is used

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BECAUSE IT IS NECESSARY to obtain more accurate data for long-term evaluation of radiation exposure, a new silver-filter film badge has been developed.* This new badge also decreases calibration time, and allows more complete monitoring of personnel.

From the important, but limited, concept of personnel protection only, a type-K dental film pack with lead cross, wrapped in lightproof, black paper and enclosed in waterproof Perma-Cel tape, was adequate when a small number of personnel close at hand was exposed to radiation. Exposures were low enough that, in cases of mixed or doubtful exposure, the film densities could be read on the radium curve. Thus the margin of error would always be for the protection of the individual.

The shortsightedness of this practice is pointed up by a review of the history of the attempt to establish a recommended tolerance level by various advisory protection committees (*1, 2*). The indefiniteness of X-ray technicians' exposure records, lack of data and measuring instrumentation, produced a maze of conjecture. When one considers the long-term experimental work now in progress on the biological effects of small dosages of radiation received over a long period of time, coupled with the fact that many hundreds of people now working in radiation will still be in the field 10 or 20 years from now, the accuracy of personnel exposure data now being kept assumes, experimentally, an entirely different emphasis. It is possible also that the type of radiation received may prove to be as important a consideration as the amount.

The old lead-cross badge has the advantages of availability, ease of assembly, low cost, and accessible history of performance both in the literature and in the experience of health-physics personnel. It quite accurately indicates under- or over-tolerance dosage, as long as proper calibrations are made, accurate instrumentation is available, and work records of personnel are easily checked.

To interpret accurate quantitative measurements in the low range of exposures (0–100 mr in two weeks), however, it is necessary to make separate calibrations for each radiation source in use, since, for the same amount of milliroentgens, the film density increases inversely with the energy of the radiation. In the range 0–1,000 mr, even the density relationships of different sources are not consistent.

An extremely rapid increase in the number of personnel and in the variety

* Work performed under Contract No. AT-04-1-GEN-12 between the Atomic Energy Commission and the University of California at Los Angeles.

of work done by the same individuals has occurred at this project. Service monitoring for other groups is now done by our Health Physics Department, with individual contacts impossible. These developments, combined with a long-range, experimental-value viewpoint of exposure records, make current badge limitations more unsatisfactory.

Experiments. Several experiments were originally set up in an attempt to simplify the film-badge monitoring technique. One of the main goals was to find a simple method for making film response proportional to the quantity of the radiation and independent of the energy of penetrating radiations.

A series of experiments with various types of crystals, arranged so that a thin, even screen resulted, was tried with various types of film having different sensitivities to visible light and X-rays. The object of these preliminary experiments was to take advantage of the visible light produced by the fluorescence of these crystals when exposed to penetrating radiations. Results indicated that the fluorescence effect was ineffective at the low exposure levels, and that this approach did not promise a quick solution.

Another series of preliminary experiments, making use of various metal filters in combination, indicated that a relationship between milliroentgens and film density could be established so that all film densities might be read directly as mr on one calibration curve.

Experimental work has been completed and verified by actual use on a more satisfactory type of film badge for the range of exposure encountered here. The badge consists of a silver filter ½ in. × ½ in. × 20 mils thick, bearing on its film side a small lead shield 21 mils thick. Of the various thicknesses of silver tried, the optimum thickness proved experimentally to be 20 mils. The filter is used in front and back in exact juxtaposition except for the lead shields. The temporary filter used experimentally is shown in Fig. 1.

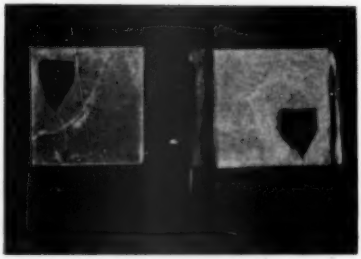


FIG. 1. Temporary filter used experimentally, is made of 6 mils of black tape, 7 mils clear x-ray film, 5 mils Scotch tape, 20 mils silver, and 21 mils of lead

The advantages of this filter over the lead cross filter are: (1) Identification of the energy of the source of gamma or X-radiation, (2) Decrease in time necessary for making calibrations, and (3) Greater accuracy of interpreting mixed-exposure badges.

Identification of Source Energy

The most common exposures encountered here are 250-kv X-ray scattered radiation, 85-kv X-ray scatter, and radium, for the range of 0–300 mr for a two-week period. Examples of four distinctive types of exposures—including uranium—are shown in Fig. 2. For the same exposure in milliroentgens, it is seen that the uranium badge shows only marginal film density; the 85-kv scatter badge shows marginal density, density under silver and no shield; the 250-kv scatter shows marginal density, silver area density and a light shield; and the radium-exposed badge shows marginal density, silver area density and an intensified shield.

The dark emblem identifying radium is explained by the action of secondary electrons from the back lead shield. Since the radiation from uranium does not penetrate silver at all, uranium badges are also distinct from the others.

A photograph of films exposed to the

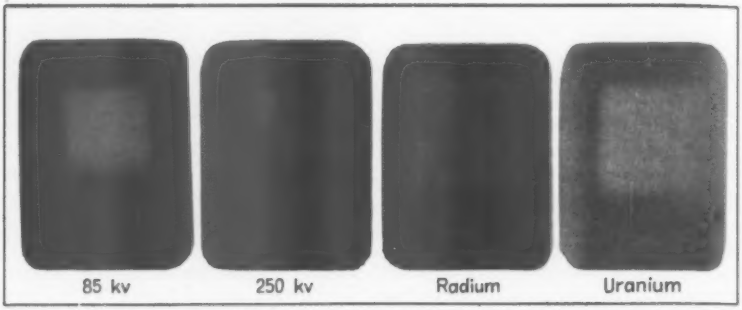


FIG. 2. Maximum permissible two-week exposures (600 mr) for different sources

radiation sources listed in Table 1 for the same range of exposure (0–1,000 mr) is shown in Fig. 3. This illustration indicates how the filter combination provides a quick, visible identification of the source.

Further identification of the energy of the source of radiation is sometimes necessary in badges of such low exposures that the visible emblems are not so clearly indicated, and in the interpretation of mixed-exposure badges, which will be discussed later. The ratio of the net density in the silver area to that of the marginal area was found to be distinctive for each energy of gamma radiation. The ratios were so widely separated as to be distinctively identifying. This ratio plotted against exposure is shown in Fig. 4.

A composite of this graph for films processed on different dates over a period of months shows how well this identification can be duplicated (Fig. 5).

Direction of radiation. The fact that the lead shield in the filter combination also indicates the direction from which radiation (above 100 kv) is coming is valuable in location monitoring. Gamma or X-radiations of an energy similar to that of 250-kv scatter will make the upper shield light if it comes from the direction the badge faces, and the lower shield light if it comes from the opposite direction. Gamma radiation of an energy similar to that of radium will intensify the lower shield if the radiation comes from the direction the badge is facing; the upper shield is intensified if the radia-

TABLE 1

Radiation Sources for Film-Badge Exposure

Radiation	*Filtration*	*Source-Badge Distance*
85 kv, 5 ma	0.75 mm Al inherent	176 cm vertical to floor 125 cm diagonally to badge holder
250 kv, 15 ma	0.21 mm Cu inherent	30 cm vertical to table 188 cm diagonally to badge holder
Radium, 10 mg	0.5 mm Pt Iridium plus 7.0 mm Lucite shield	20 cm horizontal

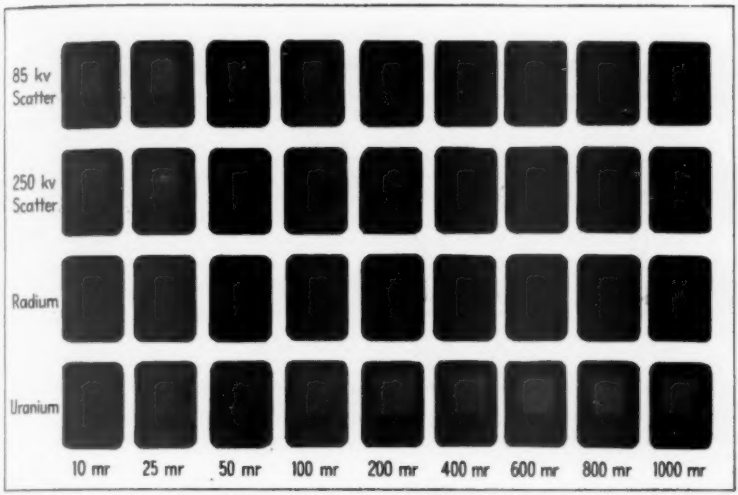


FIG. 3. Films exposed with silver filter and lead shields to sources of varying energies

tion comes from the opposite direction.

Films. Eastman Kodak's Type K film packets (1¼ in. × 1¾ in.) were used for this work. All films were processed for 3½ min at 66° F in Eastman Rapid X-ray developer. Densities were read on an Ansco Model 12 Densitometer.

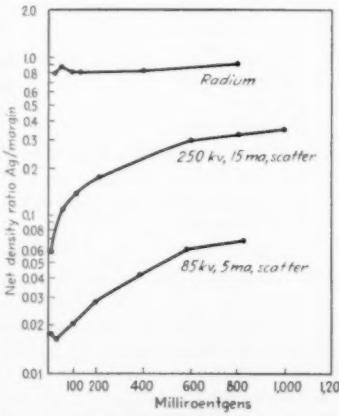


FIG. 4. Net film density ratio of silver to margin plotted against exposure in mr

Other types of film have appeared in experimental literature (*3–8*) and have been tried experimentally here, but

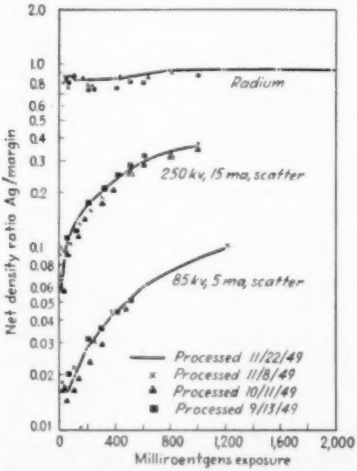


FIG. 5. Films processed in different batches give approximately the same curve of net density ratio for film under silver shield to that in margin when plotted against exposure in mr

TABLE 2

Ratio of Mass Absorption Coefficients for Silver and Lead

Approximate energy, kv	*Mass absorption (10) coefficient of Ag, density 10.5*	*Mass absorption (10) coefficient of Pb, density 11.35*	*Ratio of mass absorption coefficients Pb/Ag*
35	21	18	0.86
45	11	10	0.91
55	7	5.92	0.84
85	2.48	2.7	1.08
100	1.61	1.9	1.18
150	0.73	2.7	3.7
200	0.4	1.8	4.5
250	0.32	0.62	1.94
Radium	App. 0.06	0.08	1.33
Uranium	App. 0.03	0.04	1.33

the claims of superior linearity over Type K do not hold for the low range of exposures received at this installation. Almost all work reported on the linearity of different types of film is for a range of 0.5–10 r (*5*, *8*), and the extrapolation to zero is not valid experimentally (*9*).

Why lead and silver? The combination of lead and silver was used in the hope of making use of the difference in mass absorption coefficients of the two metals in order to make visible energy-identification areas. Table 2 shows how the ratio of the two approximates one at both high and low levels and exhibits a large change in the middle.

This is shown more clearly in Fig. 6, which compares the half-thickness values for lead and silver for various energies. The coincidence of the two curves at low kilovoltages, the sudden difference in the medium range, and the crossover at the high range explains the identifications of the 85- and 250-kv X-ray scatter radiation. The last point on the silver curve in Fig. 6 is taken from the mass absorption coefficient for tin, since there is none given for silver at this wavelength. At this level, one can safely assume that the mass absorption coefficients would be

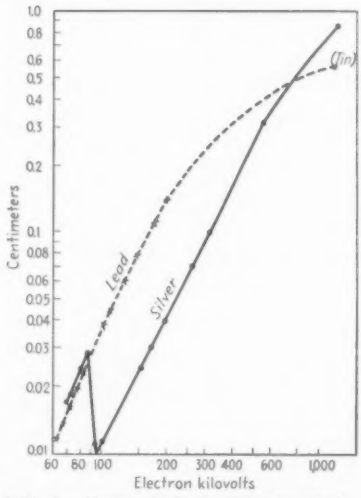


FIG. 6. Comparison of half-value thickness for lead and silver

approximately the same for two metals whose atomic weights are so close together, since at $\lambda = 0.005$ Angstroms, carbon, copper, tin, and lead have mass absorption coefficients of 0.0385, 0.0380, 0.0385, and 0.0425 respectively.

Optimum filter thickness. The experimentally proved optimum thickness of 20 mils of silver can be explained

by the following: The half-value thickness for a silver of density 11.064 for 250-kv X-rays is approximately 55 mils; that for 85-kv X-rays is approximately 9.85 mils. Obviously any filter of the half-thickness value for 250 kv will be too great for 85 kv. Since, in dealing with scatter radiation, we do not have average energies of 250 kv and 85 kv, the average energy of the 250-kv scatter radiation at the nearest realistic approach of personnel conditions of exposure was approximated at 95 kv, and that of the 85-kv chest machine at the operator's distance was approximated at 67-kv.

For 95 kv:

$$\frac{0.5}{x} = \frac{e^{-\mu_1 t}}{e^{-\mu_2 t}}$$

$$\frac{\log 0.5}{\log x} = \frac{11.82 \text{ mils Ag}}{20 \text{ mils Ag}}$$

$$\log x = \frac{20 \times -0.693}{11.82}$$

$$\log x = -1.17$$

$$x = \text{app. } 0.32$$

For 67 kv:

$$\frac{\log 0.5}{\log x} = \frac{5.5}{20}$$

$$\log x = \frac{-0.693 \times 20}{5.5}$$

$$\log x = -2.52$$

$$x = 0.08$$

Twenty mils of Ag is approximately 0.32 thickness value for 95 kv and 0.08 for 67 kv. Silver 20 mils thick then has a thickness value for 67 kv and 95 kv in the relation of 1:4. This would explain the experimental findings that the net density readings from 85-kv scatter in the silver area, when multiplied by four, can be interpreted as mr exposure on the 250-kv scatter curve.

To confirm this, an attempt was made to duplicate the scatter radiation calibration curves for 250 and 85 kv by direct radiation. Badges covering the range from 0–1,000 mr were exposed to 250, 225, 200, 175, 170, 160, 150, 125, 100, 95 and 91 kv direct radiation from the 250-kv X-ray tube. The graphs of mr vs net density were plotted together, and the 95-kv direct curve most nearly approached that for 250-kv scatter. The same mr range was covered for 80, 75, 70, 65, 55 and 50 kv direct radiation from the 85-kv chest machine, and the 60-kv curve most nearly approached the 85-kv scatter. None of the curves coincided exactly enough to substitute a direct exposure calibration technique to simulate scatter conditions in making calibrations. However, the results did reasonably confirm the explanation of the 1-to-4 density relationship between 85- and 250-kv scatter radiations filtered by 20 mils of silver.

Decrease in Calibration Time

For each exposure period it has been necessary with the old badge to make separate calibrations for 85-kv and 250-kv scatter X-radiation, radium, and uranium. All the calibrations require about 16 hours.

While the new filter does not produce the ideal of a density milliroentgen relationship that is independent of the energy of the radiation, it is a good compromise.

It was found that a master calibration curve for the range 0–2,000 mr could be made of the net density in silver area vs. mr from the 250-kv scatter calibration. The net density of the margin for badges exposed to radium was found to fit this curve exactly for most of the curve. If the net density of the dark shield is used from 800–2,000 mr, the coincidence is exact. Marginal readings are made in the center of the area below the silver filter to avoid edge effects of the films and to insure comparing densities in the same areas on different films. The net density in the silver area for badges exposed to 85-kv scatter radiation will also fit this master curve if they are multiplied by four.

Figure 7 shows this master curve and

the way in which exposures of radium, 250-kv scatter, and 85-kv scatter can all be interpreted as milliroentgens exposure from the same curve. Since the 250-kv scatter calibration can be completed in approximately 1½ hours, this results in a saving of approximately 14 hours each exposure period. For the exposures encountered in this project's monitoring, it will only be necessary to make a 250-kv calibration. A low- and high-exposure badge should be run for 85 kv and radium to confirm the relation of the ratios in regard to chemical and processing changes.

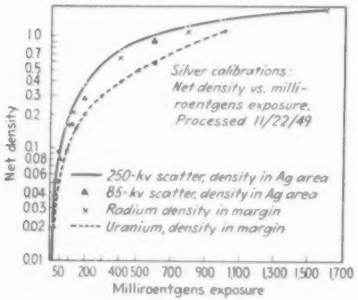


FIG. 7. Calibration curve for finding exposure in mr from film density

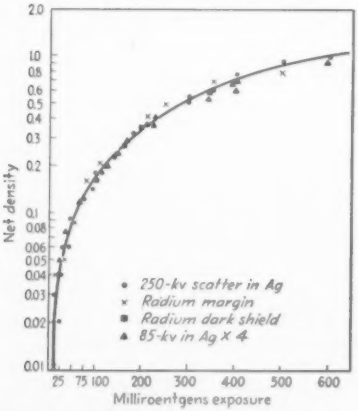


FIG. 8. Composite of four master calibration curves, showing duplication of results obtainable

In Fig. 8 the composite result of several different processings shows how accurately these results can be duplicated and how well the master curve serves for mr interpretation of density.

Interpreting Mixed-Exposure Badges

The interpretation of all personnel badges of very low exposures is generally handled sketchily in the literature, but consideration of badges of mixed exposures at low levels is either ignored or so oversimplified in theoretical discussions as to give the impression that this is a minor consideration. However, in view of the low-level exposure experimentation, this information may become important. In actual practice, not a monitoring period goes by without several mixed-exposure badges appearing. Frequently, it is a question of whether or not the wearer received an over-tolerance dose according to which calibration curve is used for

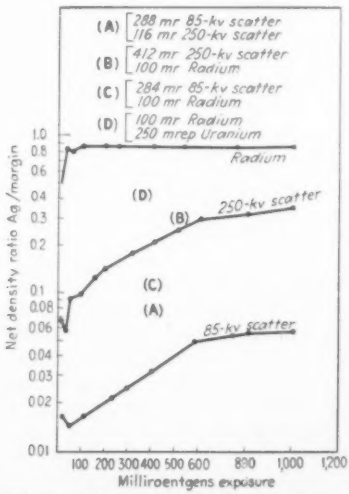


FIG. 9. Mixed exposure badges (letters in parentheses) spotted on graph of net density ratio of silver to margin plotted against exposure. See Fig. 10 for photographs of badges

reading. Tracing back for proportional work records is time consuming, and, in our experience, this questionable type of badge seems to show up most often on personnel not assigned to research work and for whom the exposure record is not a matter of routine data but of memory and opinion.

Figure 9 shows how the ratios of badges which have been exposed to radiation of more than one energy source or type align themselves in identifying positions in relation to the ratio curves. For example, the ratio of a badge which has had both 85- and 250-kv scatter radiation lies between the 85 and 250 ratio lines (A), the ratio for a badge exposed to radium and 250-kv scatter lies between the radium and 250-kv lines (B), etc.

A badge which has been exposed to radium and uranium lies between the radium ratio line and zero (radiation from uranium does not penetrate 20 mils Ag), but it also lies between radium and 250 kv (D). The presence of the dark shield confirms radium, the absence of the identifying light shield eliminates the 250-kv interpretation, and the lack of sharp outline and grainy appearance should eliminate the interpretation of 85-kv exposure if exposure of the badge were unknown.

Doubtful or unfurnished exposure histories have occured in badges monitored for off-project laboratories. On this project, care is taken to know the source of the exposure, but proportional amounts cannot be provided accurately, and accidental or unknown exposures do occur in every radiation project from time to time.

Photographs of the four badges whose ratios are spotted in Fig. 9 are shown in Fig. 10.

When the ratios are plotted on semi-log paper as in Fig. 9, the linear distance between ratio curves and the ratio of an unknown badge shows the proportion of the components. This interpolation seems to hold for all films tested with mixtures of radiations. To date no basic theoretical explanation of this has been forthcoming.

For example: the position of the ratio of badge (A) in Fig. 10 is 48% 85 kv and 52% 250 kv. When multiplied by four, 48% of the net density in the silver area corresponds, on the master curve, to 320 mr, and 52% of the net density corresponds, on the master curve, to 105 mr. Adding, 320 mr of 85 kv plus 105 mr of 250 kv gives a total of 425 mr, as compared to the known exposure of 405 mr.

Point (B) in Fig. 10, representing the ratio of the second badge in Fig. 9, lies $\frac{1}{6}$ of the vertical distance between the 250-kv and radium ratio lines. We assume $\frac{5}{6}$ of the net density in

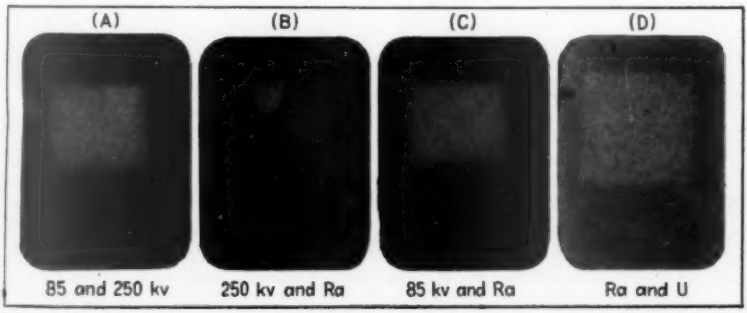


FIG. 10. Mixed-exposure badges whose density ratios are plotted in Fig. 9

TABLE 3

Comparison of Old and New Badges

kv	Measured exposure mr	Interpretation, mr: Old Type Lead-filtered	Interpretation, mr: New Type Silver-filtered
250	117	110	105
85	288	140	320
Total	405	250	425

FIG. 11. Lead-filter badge which received the same exposure as badge (A) in Fig. 10

Ag area to have been contributed by 410 mr of 250 kv and ⅙ by 110 mr of radium. This interpretation results in a total of 520 mr, as compared to the known exposure of 512 mr total.

In Fig. 11 the lead-filtered duplicate of badge (A) is shown. A comparison of these interpretations, Table 3, illustrates the greater accuracy of the silver-filtered badge interpretation.

Application

The new badges have been placed on 20 selected personnel here for the last five exposure periods. They are worn taped side by side with the lead-filtered badges, and the mr interpretation of the two badges has been done independently by two different technicians and compared. The total mr interpretation in most cases is quite close. The superiority of the silver badges has been most valuable in establishing radium exposure and in separating 85-kv X-ray scatter from beta radiation. Neither penetrates lead; only 85-kv X-ray scatter penetrates silver.

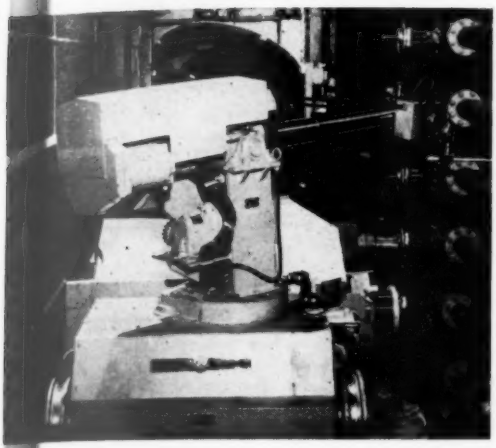
The trial period of ten weeks' data collected on actual personnel and the duplication of experimental results over six months now justifies the changing of all badges on this project to the new type and the designing of a permanent holder to replace the temporary type badge in present use.

* * *

The authors wish to thank the members of the X-ray Department of the Medical School, University of California at Los Angeles, for their cooperation in this work.

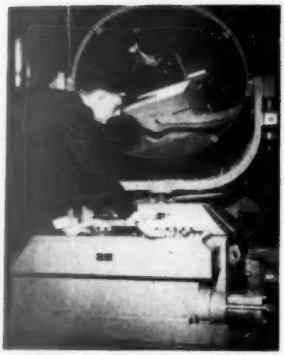
BIBLIOGRAPHY

1. H. M. Parker, MDDC-783, p. 17 (1947)
2. R. E. Lapp, H. L. Andrews. "Nuclear Radiation Physics" (Prentice-Hall, Inc., New York, N. Y., 1949)
3. R. F. Cowing, C. K. Spalding, *Radiology* **52**, No. 3, 423 (1949)
4. L. J. Deal, J. H. Roberson, F. H. Day, *Am. J. Roentgenol. Radium Therapy* **59**, No. 5, 731 (1948)
5. L. A. Pardue, N. Goldstein, E. O. Wollan, MDDC-1065 (1948)
6. F. H. Rudenberg, R. F. Cowing, C. K. Spalding, NUCLEONICS **3**, No. 6, 52 (1948)
7. Data sheet on relative speed and contrast including No-Screen films (Eastman Kodak Co., Rochester, N. Y. 1948)
8. H. O. Whipple, C. S. Hornberger, J. G. Hoffman, J. F. Nolan, MDDC-1683 (1948)
9. G. W. Morgan, NUCLEONICS **4**, No. 3, 24 (1949)
10. C. Hodgson. "Handbook of Chemistry and Physics, 30th Edition," p. 2005–2010 (Chemical Rubber Publishing Co., Cleveland, Ohio, 1947)

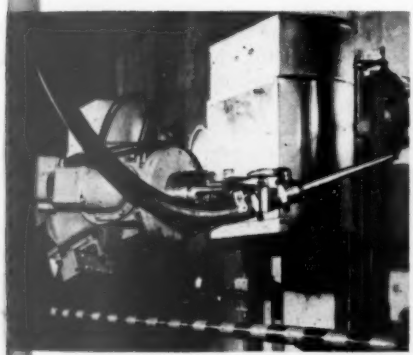


REMOTE CONTROL METHODS

The tool dolly shown—a one-armed wheeled robot—is used at the G. E.-operated Hanford Works to perform tasks in radioactive areas (NU, May '50 p. 73). The telescoping arm (1) can be extended, shortened, raised or lowered, while its prosthetic-like "hand" is capable of a wrist-bending motion, rotation and gripping. The robot can be operated from controls at a remote location, or from a panel on the dolly (2). Mirror is used for remote observation; lights on remote panel indicate hand and arm position when the machine is out of sight. Picture (3) shows how robot can be used for fire fighting.



Argonne National Laboratory has developed a stereoptic television system (4) for viewing remotely controlled operations. Twin-lens camera produces two images on screen; polarizing filters over screen and in eyeglasses enable operator to see his hidden work in three dimensions.



EXPERIMENTS WITH A 6-MEV BETATRON

FIG. 1. Betatron with vacuum chamber withdrawn

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and

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PRIOR TO announcement in 1941 of the successful operation of the first betatron at the University of Illinois, German scientists had not found a practical solution to the problem of accelerating electrons in an electric whirl field. Steenbeck (*1*), following the pioneering work of Wideroe (*2*), had been able to establish the directional field of the betatron and its stabilizing conditions. But he had failed to obtain more than a minute output from his 50-cycle set.

CONSTRUCTION

When Kerst's construction and operation of the University of Illinois betatron was revealed, work on the problem of electron acceleration was resumed in Germany. Construction of an experimental 6-Mev betatron, working at 500 cycles, was begun in 1942. Radiation was obtained from this instrument for the first time in April, 1944 (*3*). Investigations were carried out in the Electro-medical laboratory of Siemens-Reiniger-Werke, Erlangen, Germany.

To investigate the possibilities of a high-velocity electron therapy, this first experimental set was designed to permit the accelerated electrons to emerge to the outside. The main point was to arrange the injector inside the equilibrium orbit, leaving the way unobstructed for electrons about to emerge. As easy access to the injector in spite of its interior location was desired, the conventional design was abandoned, and a ceramic vacuum chamber, which may be removed from the apparatus and taken to pieces in a few moments, was employed. See Figs. 1 and 2.

The 12-in. diameter chamber, made of four ceramic* parts, is sealed by two

* "Frequenta" material, produced by Messrs. Stemag, Lauf.

Work with the German betatron described here has progressed to treatment of cancers and tumors in humans. Besides describing its construction, this article reviews preliminary physical and biological experiments and results

interior and two exterior rubber rings, and evacuated by means of a mercury diffusion pump. The internal metal layer is formed by a deposit of burnt-in silver, subdivided in both top and bottom disks into one continuous strip 8 mm wide. This is used as a heating coil for speeding up degasifying of the internal chamber walls. The electron portal, extending over roughly a quarter of the circumference, is formed by a copper foil 0.05 mm thick.

The accelerating space, the dimensions of which are given in Fig. 3, has a large radial extension compared to the diameter. With a final energy of 6 Mev, the central pole shoes will reach a saturation value of about 13,000 gauss, with 2,600 gauss at the equilibrium circuit, having a radius of 8.3 cm.

Figure 4 shows the disposition of injector electrodes and potentials applied.

Extracting the Beam

Since August, 1947, the betatron has been operated with an attachment supplying a concentrated beam of electrons (5). The problem of deflecting the beam offered some difficulties because of the comparatively large radial oscillations performed by the electrons at the end of the accelerating period. Depending on the magnitude of their radial oscillations, the electrons will become unstable on a circle situated more or less far beyond the equilibrium orbit.

It can hardly be hoped to trap all the electrons by means of a deflecting capacitor, or with a magnetically shielded guiding channel as suggested by Skaggs (6). Nevertheless, it was possible, by means of the attachment shown in Fig 5, to collect as much as 70% of the accelerated electrons.

Slightly inside the limiting circle (shown in dashes in Fig. 5) an adjustable deflecting capacitor with a field strength up to 150 kv/cm is arranged. About 20 degrees azimuthally in front of it there is an aluminium strip some 2 to 3μ thick and 0.3 mm wide, with its face at a right angle to the electron beam. The inner edge of this strip is about 0.1 mm nearer the center than the face of the deflector. Thus the rotating elec-

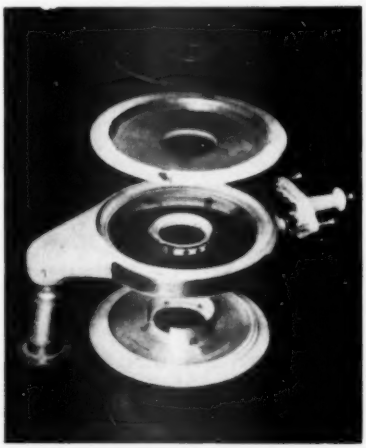

FIG. 2. Component parts of vacuum chamber assembly showing rotary symmetrical pole shoes. Seen from top to bottom: upper pole shoe with built-in disrupting coil; top disk; exterior ring with pumping socket, wide electron portal (in front) and deflector (at the observer's right) with insulated high voltage through-conductors; interior ring, carrying injector and electric leads; bottom disk with attached metalized ring for screening injector leads; lower pole shoe

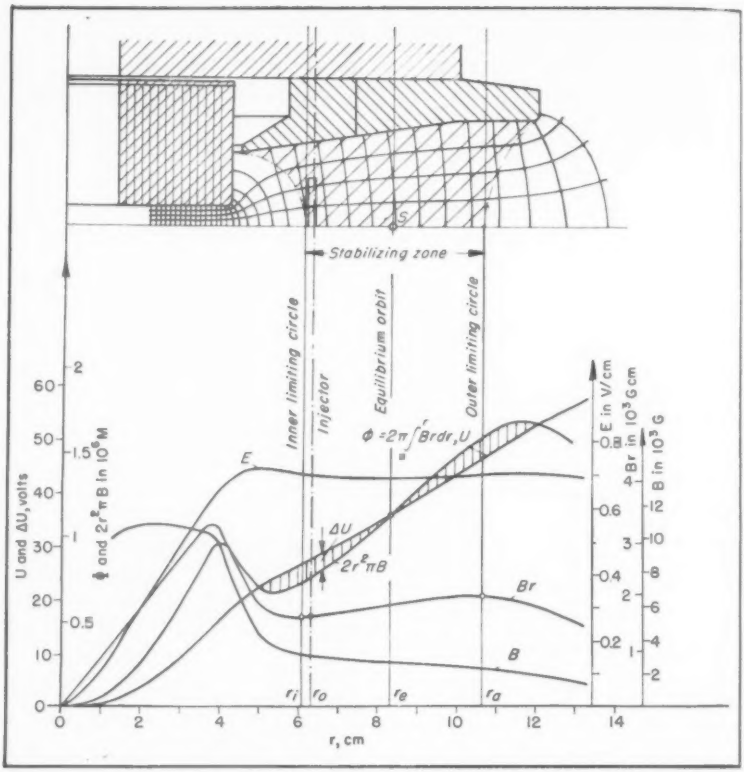

FIG. 3. Above: Cross section of pole shoe, with lines of force and equipotential surfaces. Below: Results of measuring magnetic field at 6 Mev by means of concentric measuring loops. B = flux density, ϕ = flux, U = gyratory voltage, $E = U/2r_r$, electric gyratory field strength

trons whose orbits are widening out very gradually in comparison to the number of cycles performed during the increase of the boosting current, will impinge on the aluminium foil before touching the deflector. The electron beam is split up by multiple scattering within the foil into a narrow pencil of a half-value aperture of less than one degree, the outer half of which is at once trapped by the deflector. Electrons from the inner half of the pencil will perform another few radial oscillations, finally entering the deflector—partly after having undergone another scattering process in the foil.

Placing the scattering foil at the same central distance as the inner face of the deflector and then moving it forward by a mere $\frac{1}{10}$ mm causes the electron output to jump suddenly to the sevenfold value. Continuing the movement, however, produces a slow decline. See Fig. 6. Removing the scattering foil completely and placing the deflector beyond the limiting circle makes it impos-

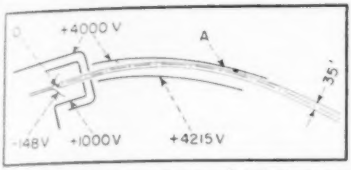

FIG. 4. Cross section of injector assembly, showing deflector, potentials applied, and pencil of electrons emerging azimuthally

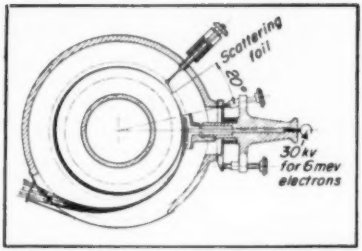

FIG. 5. Horizontal section of vacuum chamber showing scattering foil and deflector

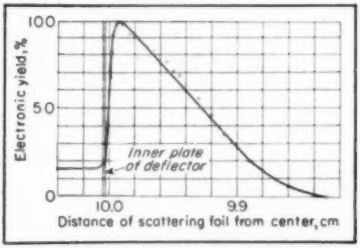

FIG. 6. Steep increase and slow decrease of electron beam output caused by advancing scattering foil from outside

sible to extract more than 25% of the accelerated electrons. The mean electron current emerging from the copper-foil portal was measured by trapping the beam in a screened lead cage and passing it through a galvanometer. The highest reading obtained was 1×10^{-7} amp.

Results of dose measurements carried out in the emerging electron beam are shown in Fig. 7. In the immediate vicinity of the portal, as much as 300 kr/min were measured.

RESEARCH

Upon cancellation of the impounding order of the apparatus by the Allied Military Government in 1947, various physical, biological, and medical investigations were carried out at the II. Physics Institute of Göttingen University.

Physical Experiments

For tracing the path taken by the electrons inside the betatron immediately before and after disruption of the equilibrium orbit, the staining of alkali halide crystals under the impact of electrons was utilized. In lieu of a target, a small crystal bar 50 mm in length, and of 7×8 mm cross section was placed in the vacuum chamber. After irradiation by electrons a staining of the crystal as diagrammed in Fig. 8 will be observed.

The inner flank, situated at the distance r from the center of the betatron, is stained over its entire area in consequence of both straying scattered, and oscillating electrons. Contiguous to its leading edge, the front is stained evenly over the breadth b up to a depth d, corresponding to the range of electrons in KCl, while the portions outside these limits remain quite clear. This outer line is the place of impact of those electrons which, at their previous revolution, has just managed to clear the crystal's inner flank. The distance b from the leading edge is hence equal to the pitch of the dilating electron spiral at the place r. By altering the radial distance of the crystal bar, it is possible to trace the position of the equilibrium circuit and of the spiral course in the neighborhood of the limiting circle.

The position of the equilibrium orbit follows from the fact that, with equal

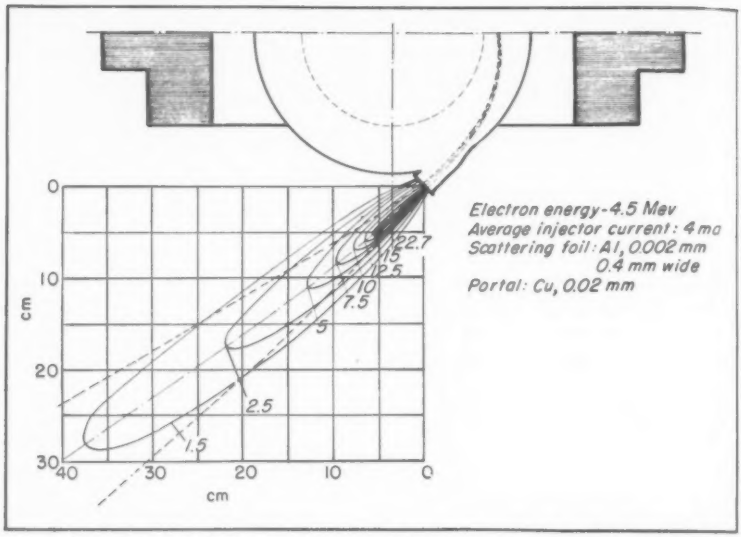

FIG. 7. Curves of equal ionization of air caused by electron beam. Figures given refer to kiloroentgens per min. Width of each square equals 5 cm

exposure times, the intensity of staining—then confined to the crystal's inner flank—will become less on approaching the equilibrium orbit, vanishing completely in its immediate vicinity. In this way a value of $r = 84$ mm was found for our betatron, as against a value of 83 mm based on calculations. It is also a simple matter to find the axial width of the electron beam from the height of the stained portion of the crystal.

A distinct advantage of this method is that the depth of the stained area makes it easy to differentiate, by their range, high-energy electrons from their slower partners belonging to the beginning of the accelerating period.

As early as in 1944 the X-radiation occasioned by betatron-accelerated electons had been utilized to study the neutron yield of the nuclear photo effect in Be and D in dependence on the terminal energy of the continuous X-ray spectrum up to 5 Mev (*8*). Later on, installation of the electron deflector made it possible to prove the direct splitting of a deuteron by electrons, a process known so far only in respect to Be by the investigations of Collin, Waldmann, and Wiedenbeck (*9*).

Cuvettes of plastic material containing D_2O were placed against the electron portal, and the neutron yield measured in dependence upon the thickness of D_2O. As a comparison, the same relation was measured in the D (γ_0,n) process produced by X-rays inside and outside the D_2O. To this end the D_2O was shielded by a piece of lead or, on the other hand, used as a dissolvent for uranyl nitrate. An analysis of the graph obtained will reveal that in pure D_2O a direct splitting of the deuteron by electrons as well as the photo effect will take place. With thin layers, both effects are of the same order of magnitude. At 3.8 Mev the cross sec-

tion for the electronic effect was found to amount to 10^{-31} to 10^{-30} cm², the effective electronic current being about 5×10^{-8} amp.

Further experiments were made to measure, by means of a beta-spectrometer, the braking effect (energy loss per cm path) of Be, C, H_2O, Fe, and Pb upon electrons of 2.8 and 4.7 Mev (*10*). Hitherto this quantity, and its dependence upon the energy, had been based, as a rule, upon the calculations of Bethe and Bloch. Fermi, and Halpern and Hall, respectively, showed that these values needed some correction, since the field of the electrons passing through matter is weakened by polarization of the atoms produced. With low energies this effect should be particularly noticeable in carbon.

By using a 60-degree sector magnetic field as a beta-spectrometer and measuring the energy distribution of the electrons emerging from the betatron before and after passing the respective substance, both the mean and the most probable energy losses of electrons per cm path were ascertained (Fig. 9). The spectrum of the unweakened electron beam is found to have a linear half-width of about 50 kev. This lack of definition is, on the one hand, due to the electrons' having already passed the betatron portal and the spectrometer's entering window in addition to 6 cm of air, totalling 23 mg/cm², producing a broadening equal to 25 kev; on the other hand to the characteristic width of the spectrometer on account of its resolving power, approximately 15 kev. It follows that the energy of the electrons after acceleration is well defined within a few per milles. The braking capacity of carbon was found to stray off the uniform trend with Z, in accordance with the Halpern-Hall theory. Spectra identical within the accuracy of measurement were obtained for graphite and diamond.

The biological effect produced in a

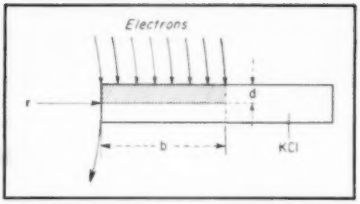

FIG. 8. Staining of crystal bar in vacuum chamber by electron irradiation

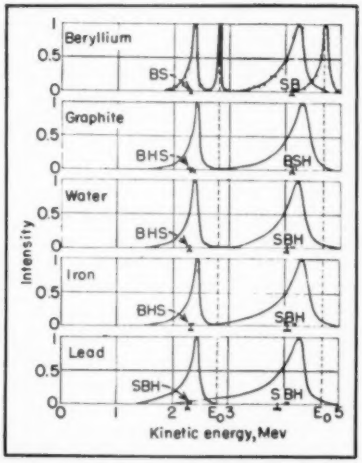

FIG. 9. Energy spectrum of electron beam after passing C, H_2O, Fe, Pb with primary energies of 2.7 and 4.8 Mev. At E_0 spectrum of unweakened beam. S is position of mean loss in energy according to experiments, B and H according to theories of Bethe-Bloch and Halpern-Hall respectively

body by electronic irradiation is governed by the number of ions formed per mass unit of penetrated material. This quantity is defined as "dose." For applying electron rays in biology and medicine it is essential to know the density distribution of ions within the material irradiated, as well as the parameters which it depends on. Glocker (*11*), experimenting with electrons of Brasch's and Lange's impulse generator for 1.8 Mev, found in 1934

that the ionizing density within material increases up to a maximum and then becomes zero together with the range of electrons. This fact was verified by various experiments made recently with the betatron. Gund and Wachsmann (*12*), using a small ionization chamber and a wax phantom, ascertained the depth dose distribution at various electronic energies, while Glocker et al. (*13*) investigated this same problem at 5 Mev, employing the well known killing of eggs of Drosophila mel. as a dosage indicator.

Finally, the distribution of an electron beam and the formation of an ionization maximum was studied in detail by Berger and Paul (*7*). Once again a KCl crystal was used as testing material; its staining under electron rays was examined. Secondary electrons detached by ionization will induce violet centers (neutralized K atoms) at disturbances of the lattice, the number of which will be representative of the number of ions formed primarily. The dose may thus be found by measuring the density of color centers at every point by means of a spectral photometer.

It was found that the forming of a dose maximum in the interior of the body depended on the size of the field irradiated, and is caused by the superposition of the elemental "bottles" of scattered electrons. Whatever energy was applied, the maximum was located at a depth approximating one third of the electron range, its magnitude relative to the surface dose increasing with the energy applied throughout the examined range of energies between 2 and 5 Mev. In Fig. 10 the depth dose distribution inside a crystal irradiated is shown for various diameters of the electron beam.

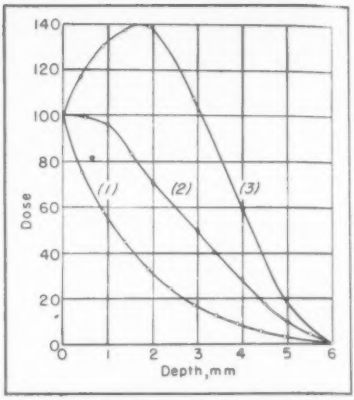

FIG. 10. Distribution of depth dose in KCl crystal irradiated with electrons (3 Mev). Diameter of electronic beam (1) ⅙ *R*, (2) ⅓ *R*, (3) 2 *R*. (*R* = Electron range)

Biological Reactions

The physical peculiarities of fast electron radiation already discussed suggest that its therapeutic application offers, in many cases, advantages over conventional X-ray therapy. As a prerequisite, the question of what qualitative and quantitative differences exist in the biological action of high-energy electrons as compared to the usual 200-kv X-radiation had to be examined. While there are, in respect to individual physical processes, no qualitative differences between electrons of high energy ($E > 1$ Mev) and secondary electrons released by an X-radiation of 200 kv, qualitative differences do occur regarding the differential ionization, i.e., the number of ions formed per cm path. This quantity decreases rapidly with increasing electron energy up to values of $E \approx mc^2 = 500$ kev, from which point onwards it remains practically constant in the range under investigation up to 20 Mev. The mean separation of ionizations in water is in this region $\sim 0.2\mu$ whereas, in the region of secondary ions of a 200-kv X-radiation (average energy $\sim$20 kev), it is as small as 0.02μ, and less.

In order to induce a certain reaction in a biological unit, the target theory

Relative Biological Efficiency of Fast Electrons Compared to 200-kv X-rays

Material	*Reaction*	*Effective Electron Dose (r units)*	*Effective X-ray Dose (r units)*	*X-ray Dose/ Electron Dose*
Bacterium coli comm.	Killing of 50%	2,200	3,200	1.45
Drosophila eggs, 3 h. old	Killing of 50%	195	205	1.0
Drosophila eggs 4 h. old	Killing of 50%	1,225	460	0.4
Drosophila eggs, $7\frac{1}{2}$ h. old	Killing of 50%	1,060	825	0.8
Drosophila chrysales	Killing of 50%	3,050	2,800	0.9
Roots of barley	20 chromosome bridges in 100 mitotic cells	1,600	1,300	0.8
Roots of barley	50 chromosome fragments in 100 mitotic cells	1,950	1,600	0.8
Germinating barley	Inhibition by 50% of growth in length of cotyledons	3,100	1,700	0.6
Germinating barley	Inhibition of growth in 10% of all irradiated seeds	4,800	2,600	0.5
Barley roots	Reduction in length by 30%	3,000	1,500	0.5

demands a certain number of ionizations or excitations to occur (single or multi-hits) within a certain part of it, the so-called target. As the linear dimensions of these targets are something between 0.1 and 0.01μ, it seems obvious that the different electronic energies may vary in their biological effect. In case of various reactions of different character being possible in a biological unit, fast electrons will preferably induce those which require, within a given target, a small number of simultaneous ionizations.

An attempt to clarify these points was made in cooperation with the Radio-biological Department of the Göttingen University Gynaecological Hospital under the direction of G. Schubert. Various biological reactions of animal and vegetable materials were investigated when induced both by fast electrons and 200-kv X-rays (*14*). The results obtained with the respective reactions were compiled in the table on this page. In all cases accurate dose-effect curves were taken, examples of which—referring to the growth of cotyledons of barley seedlings or the killing of drosophila eggs—are given in Fig. 11.

The killing of eggs, while showing no qualitative differences in the shape of the survival curves, i.e., in respect to the number of hits, produces quantitative differences regarding the half-value dose, the age of the eggs playing a decisive role. Experiments carried out so far permit some statements to be made on the relative biological efficiency of fast electrons in comparison to 200-kv X-rays. This is to be understood as the ratio of the X-ray dose to the equally effective electronic dose, both measured in identical roentgen units and referring to a certain biological effect. The table shows that, for somewhat complicated reactions, this ratio is mostly below one, i.e., electrons are less effective; it equals unity only in the killing of drosophila chrysales and 3-hour old eggs, reaching 1.4 for bacterium coli.

Qualitative differences were observed in the growth in length of cotyledons of germinating barley irradiated with fast electrons and X-rays (Fig. 12). Whereas 200-kv X-rays result only in

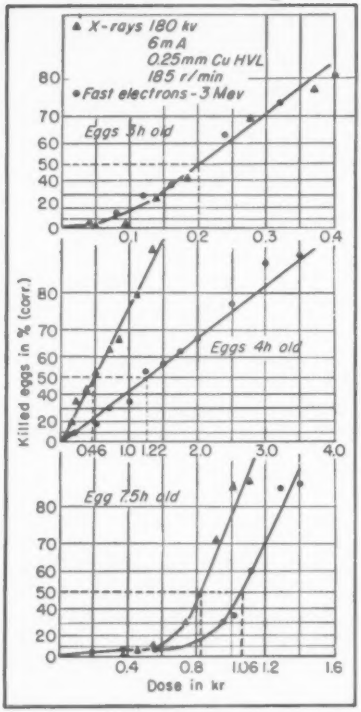

FIG. 11. Percentage of killed eggs of drosophila mel., after irradiation with electrons and 200-kv X-rays

an inhibition of growth, electron doses up to about 1,600 r were found to stimulate growth. When examining the length distribution of cotyledons ten days after irradiation, the distribution function of X-rayed seedlings is found to be a good deal narrower than that of those irradiated by electrons. With small and medium degrees of damage, fast electrons show a broader spectrum of efficiency, which fact is also observed when irradiating the Ehrlich carcinoma of mice.

The effect of fast electrons upon mitotic processes was investigated in the cornea of salamander larvae and in

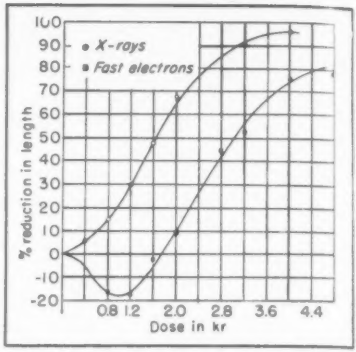

FIG. 12. Length of cotyledons of germinating barley after irradiation with electrons (3 Mev) and X-rays (200 kv)

the root-tip cells of germinating barley. Again it is observed that with equal doses administered, 200-kv X-rays induce greater pathological changes in cell nuclei than fast electrons. Since above 1 Mev the differential ionization is practically constant, equal doses of 2- and 5-Mev electrons should have the same biological effect. This is verified by experiments concerning damages induced in germinating barley.

Therapeutic Application

If, then, the favorable dose distribution in the interior of a substance irradiated by fast electrons suggests that an electronic therapy will offer certain advantages, it is also possible, in view of the biological experiments outlined here, that qualitative differences in the effect of fast electrons as compared to X-radiation of lower energy may concur, favoring healing processes. Observations made on the Ehrlich carcinoma of mice may be interpreted in this direction.

Fifteen days after grafting the carcinoma, some 700 mice were given a single dose of 4,000 r of electrons (3 Mev) or X-rays (200 kv, 0.25 mm Cu). While pathological and histological examinations revealed no fundamental

differences for the two types of rays employed, unmistakable differences were noticed in the intensity of reactions in tumor cells and connective tissue, all reactions becoming manifest more quickly and sharply after electronic irradiation than in checks subjected to X-rays. A swelling of tumor cells is observed sooner, whereas a conglomerating of cell nuclei occurs less frequently.

The most striking point, however, is the more intensive reaction of connective tissue. On the second day after irradiation by electrons a swelling of the connective tissue is already seen, subsequently invading the cancerous tissue mesh-like from the periphery. In addition, a longer lasting inhibition of the mitosis of tumor cells is observed.

Cancer Treatment in Humans

Following the preparatory physical and biological investigations which have been described, the treatment of human cancers was begun in April, 1948. Because the maximum range in tissue of 6-Mev electrons is only 3 cm ($R = 0.5$ [cm/Mev] $\times E$), treatment was confined to cancers of the skin and metastatic lymph nodes near the surface. Work was carried out in cooperation with the Göttingen University Dermatological Hospital (*15*).

Up to September, 1949, a total of 43 cancers were given single doses of from 1,000 to 2,000 r at a dosage rate of 1,000 r per min. Among these there was a number of keratotic squamous epithelium tumors, seven of them being cancers of the lips and basaliomata. Some cancers had a diameter exceeding 4 in.

The process of the electron-induced reactions is considerably stronger and speedier than with X-ray treatment. After approximately eight days a strong erosive reaction commences, fading out again about six weeks after treatment. During this interval a leveling of the surface takes place and the tumor vanishes completely.

The electronic energy, and thus the range, was adapted in each case to the extension in depth of the tumor. The rays were adjusted in such a way as to produce, at the tumor base, a dose equaling the surface dose, the tumor base being thus located at $\frac{2}{3}$ of the electronic range.

In addition to carcinomata, several cavernous hemangiomata of infants and keloids were irradiated with excellent success. The surprisingly good curative results of electronic irradiation may be attributed to a dose distribution being almost ideal for superficial therapy, and also, in regard to cancers, to the increased growth of connective tissue. The dose increase up to a peak at one third of the electronic range saves the skin from overloading, while the steep decline of the dose curve and the easily adjusted range of electrons fully safeguards the healthy tissue behind the focus of disease.

BIBLIOGRAPHY

1. M. Steenbeck, *Naturwissenschaften* **31,** 234 (1943)
2. R. Wideröe, *Arch. Elektrotech.* **2,** 387 (1928)
3. K. Gund, *Nachr. Ges. Wiss. Göttingen, math. physik. Klasse* **9** (1946)
4. K. Gund, Diss. Göttingen (1947 unpublished)
5. K. Gund, H. Reich, *Z. Physik* **126,** 383 (1949)
6. L. S. Skaggs, G. M. Almy, D. W. Kerst et al., *Phys. Rev.* **70,** 95 (1946)
7. H. Berger, W. Paul, *Z. Physik* **126,** 422 (1949)
8. H. Kopfermann, W. Paul. *Nachr. Ges. Wiss. Göttingen, math. physik. Klasse* (1946)
9. W. Paul, *Naturwissenschaften* **36,** 31 (1949)
10. W. Paul, H. Reich, *Z. Physik* **127,** 429 (1950)
11. R. Glocker, *Z. Physik* **35,** 574 (1934)
12. K. Gund, F. Wachsmann, *Strahlentherapie* **77,** 573 (1948)
13. R. Glocker, K. Gund, et al., *Strahlentherapie* **78,** 321 (1949)
14. W. Paul, G. Schubert, *Naturwissenschaften* **37,** 156 (1950)
15. H. G. Bode, W. Paul, G. Schubert, *Strahlentherapie* **81,** 251 (1950)

Body Radium Content of Individuals with No Known Occupational Exposure*

Incidence of bone cancer from radium ingestion is a problem industry cannot ignore. Thus health physicists must constantly review recommended safe exposure levels for radium workers in light of new comparative data such as that offered here on body content of persons not exposed occupationally

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PRIOR TO the present report, the only data in the literature on the subject of the radium body content of human subjects not exposed occupationally are contained in a paper by Krebs (*1*). He found a range of from less than 1×10^{-9} to 4×10^{-8} gram of radium (average 1.4×10^{-8} gm) per whole body for a group of 18 deceased individuals who had resided in various regions of Germany.

The size of the values reported by Krebs is a matter of some concern since his highest value of 4×10^{-8} gm is 40% of the recommended maximum permissible body content (1×10^{-7} gm) of radium for dial painters and other workers occupationally exposed to radium poisoning. If this finding is representative not only of Germany† but may be extended to the world's population as a whole, health physicists may speculate about two possible consequences of the narrow gap between the highest radium level found in unexposed individuals and that level regarded as safe for radium workers.

The first consequence relates to the possibility that radium normally accumulated in the bony skeleton may be the causative factor in cases of osteogenic sarcoma which appear to arise spontaneously.

As a result of the pioneering investigation by Aub, Martland, and Evans (*2*), who studied the injuries sustained by radium dial painters and other radium workers, it is known that radium ingestion may result in bone cancer. The lowest radium body content for which these investigators were able to identify neoplastic bone changes was 5×10^{-6} gm radium. Seven patients showed no clinical symptoms of poisoning although they had body contents of from 0.2 to 5×10^{-7} gm and an exposure history of from 7 to 25 years.

As specified by these findings, there might appear to be a safe interval between Kreb's value of 4×10^{-8} gm and the radium level at which bone changes have been known to occur. However, it must be recognized that Krebs's sample was a small one and that

* This paper is based on work performed under contract with the U. S. Atomic Energy Commission at The University of Rochester Atomic Energy Project, Rochester, N. Y.

† One of the criteria which governed selection of material, as stated in Kreb's paper, was that the subjects be representative of various regions of Germany.

there may well exist a biological range of sensitivity to damaging radiations and that, therefore, some unexposed individuals may have both a higher radium body content and a greater sensitivity to damage by ionizing radiations than existing measurements reveal.

The second consequence relates to problems of waste disposal from facilities producing or using large amounts of radioactive materials. Specifically, the health physicist is interested in the extent to which food and water supplies may be contaminated without producing any injurious effects on organisms, including human beings, subsisting in the vicinity of the contamination sources.

Stating the case for radium, it might be argued from Krebs's data that the naturally existing level of radium could be little more than doubled before the fixation of radium in bones of exposed human beings would approach the maximum permissible level. The permissible increase of other long-lived bone-seeking radioactive elements such as Sr^{90} could be calculated on an equivalent radium basis.

Since considerations of this sort may be matters of general concern and since the king-pin of the train of arguments is the value of the radium body content of the unexposed human individual, it was decided to supplement the existing data by experiments performed on material available locally.

METHOD

Radium determinations were made on the bodies of 25 adult individuals and 6 stillborn infants. Pertinent biographical data were obtained by examining the records of the state or county institutions in which the subject died or by correspondence with relatives or friends of the deceased. In a few cases, the only available history was contained in a brief police report.

Ashing Procedure

The bodies were, for the most part, embalmed and had been used for instruction purposes in an anatomy course. Of the 25 adult bodies, 4 were cremated directly after death without embalming. The radium results from these 4 bodies showed no trends or consistent differences from the results obtained with the other 21 bodies. In all cases, the bodies were cremated without further dissection of muscle tissue from the skeleton or removal of organs. Accordingly, the ashes are derived from the more-or-less complete body.

The first 5 bodies were ashed on the crematory floor itself. The remaining 20 adult bodies were cremated on a $\frac{1}{16}$-inch stainless steel plate, 2 feet wide by $6\frac{1}{2}$ feet in length. Depending upon the condition of the body, the ashing procedure required from one to two hours at a temperature near 870° C. The ashed remains were ground twice in a hand grinder, weighed, thoroughly mixed, and a sample was taken for further processing and analysis.

Digestion Procedure

The sample of ashed bone was ground to a fine powder in a mortar, and a 20-gm aliquot was placed in a 300-ml Kjeldahl flask. To the ash were added 50 ml of concentrated nitric acid and 80 ml of concentrated perchloric acid. The flask contents were then boiled until the reaction was complete. Since an insoluble residue usually remained, the contents of the flask were transferred to a centrifuge tube, with 50 ml of 0.5*N* hydrochloric acid used as a wash solution. It was centrifuged for 10 min at 1800 rpm, the supernatant was decanted and saved, and the residue was transferred to a 130-ml platinum crucible and dried on a hot plate. To the dried residue were added 10 ml of 50% hydrofluoric acid, and the crucible contents were again taken to dryness;

20 gm of anhydrous sodium carbonate were added to the material remaining in the crucible, and this mixture was fused for one hour at 900° C in an oven. The cooled crucible and contents were submerged in 100 ml of 1:1 nitric acid in a beaker. When the reaction was completed, the crucible was removed and rinsed with a small quantity of distilled water into the beaker. The original supernatent was combined with the contents of the beaker, and the total solution was heated to dryness. The dried salts were made up to 150 ml volume with 0.5*N* hydrochloric acid. If turbid, 5 to 10 ml of 1:1 nitric acid were used to clear.

The ashes of 6 stillborn infants were treated in the same manner as that described above except that the ashed samples gave clear solutions after the initial acid digestion. Therefore, the remainder of the procedure was omitted.

Measurement Procedures

Analysis of the radium in solution was performed by measuring the activity of radon gas accumulated in the solution during a known time interval. The standard or the unknown radium solution was placed in a 300-ml round-bottom flask, heated to boiling, and cleared of radon by bubbling room air through the solution for a 15-min period (see Fig. 1). The sealed flask was allowed to accumulate radon for a measured time period. For experimental samples, this period was about three half-lives (11–12 days). A second deemanation was performed in which compressed air* (aged in the gas bottle for more than one year) was used as the carrier to sweep the radon into a one-liter glass bulb.

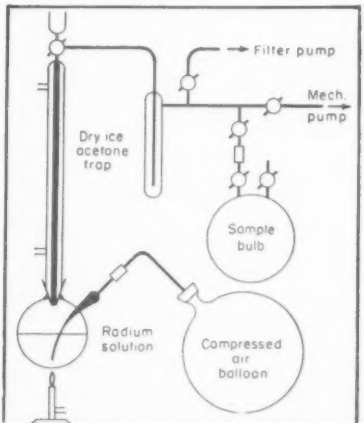

FIG. 1. Apparatus for collecting radon gas sample from radium solution

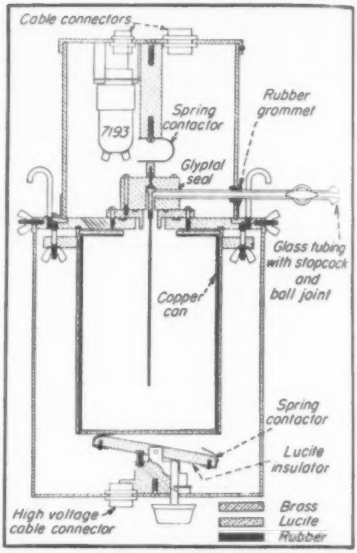

FIG. 2. Gas chamber used in measuring radon activity

* It was not considered necessary to use compressed air in the first boil-off as only a small volume of room air, about 200 cc, would be trapped above the solution and within the condenser, and this radon would have decayed to $\frac{1}{8}$ of its original strength by the time the sample was measured. Since the concentration of radon in the laboratory air is about 0.2×10^{-12} curies per liter, the 0.04×10^{-12} curies of radon which would be left in the space above the solution after the initial boil-off would have decayed to 0.005×10^{-12} curies at the time of measurement three half-lives later. This quantity is so small that it may be neglected.

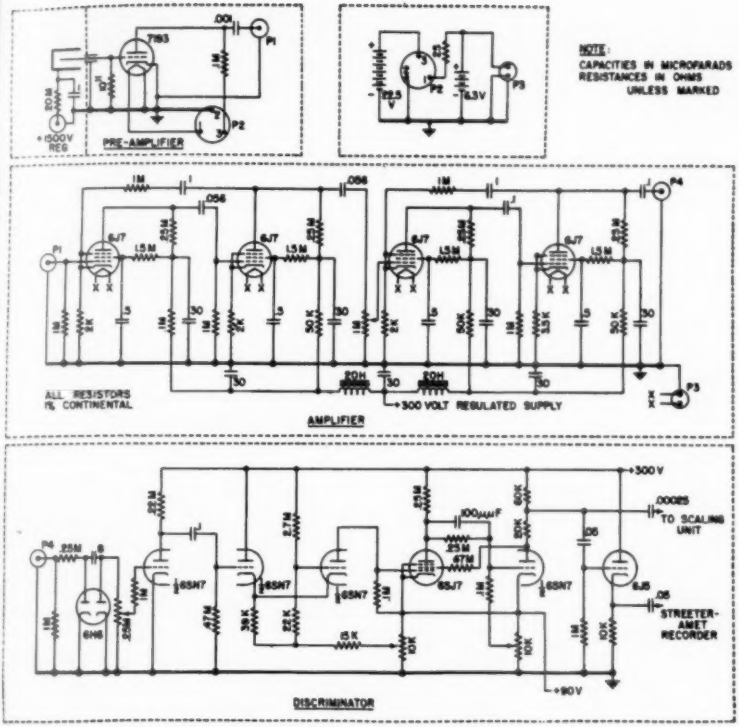

FIG. 3. Circuit diagram of amplifier and discriminator units

The radon gas was introduced into the counting chamber (see Fig. 2) by means of water displacement through a solid CO_2 refrigerated water trap. Tank nitrogen was flushed through the line to bring the gas in the two-liter chamber to atmospheric pressure.

The electronic circuits used are illustrated in Fig. 3. The preamplifier circuit uses dry cell batteries for power supply and a 6.3-volt storage battery for filament supply. The preamplifier vacuum tube is mounted directly above the gas chamber, as indicated in Fig. 2. The amplifier is a feedback amplifier of more or less standard design with all the filament voltages derived from the storage battery. The discriminator circuit is modified from an original circuit design by Lewis (*3*). The output of the discriminator is fed into both a standard scaler circuit (consisting of two decade banks backed up by a mechanical counter) and a Streeter-Amet traffic recorder.

It has been practice in our laboratory to make the central electrode negative with respect to the outside wall of the chamber. The pulses recorded are, therefore, due to the positive ions formed along the path of the alpha particle and collected at the central electrode. No gas multiplication occurs at the collecting voltage and chamber

TABLE 1
Calibration Data

Sample	*Counts per minute per* 10^{-12} *curie radon*			
10^{-12} *curie radon*	*First hour*	*Second hour*	*Third hour*	*Fourth hour*
Counter 1				
14.92	2.03	2.57	2.85	2.90
11.37	2.22	2.70	2.84	3.01
19.43	2.19	2.65	2.89	2.89
19.04	2.10	2.72	3.02	3.00
14.72	2.14	2.71	2.90	3.04
Average	2.14	2.67	2.90	2.97
Per cent theoretical*	63.0	67.8	68.3	69.6
Counter 2				
19.70	2.22	2.64	2.87	2.85
9.75	2.05	2.45	2.81	2.84
15.71	2.11	2.52	2.73	2.84
14.97	2.13	2.62	2.82	2.98
14.95	2.08	2.48	2.77	2.64
Average	2.12	2.54	2.80	2.83
Per cent theoretical*	62.4	64.5	66.1	66.3

* The "theoretical" cpm is assumed to be the sum of the α dpm from Rn plus one half of the α dpm from RaA + RaC'. Increase in % theoretical count with time may depend on the greater average amplitude of pulses coming from RaA and RaC' as compared with pulses from radon disintegrations. This increase in amplitude might be expected on a basis of energy and on the basis of geometry since RaA and RaC' deposit on the central wire.

geometry is used. The pulses are consequently slow and quite variable in shape and height.

Following equipment design used by Dr. Robley D. Evans of the Massachusetts Institute of Technology, we adjusted the collecting voltage and the height gain selector in the discriminator circuit to reject about 30% of the pulses on an amplitude basis. By so doing, it was possible to discriminate against the background pulses originating from the radium contamination of the wall of the chamber can, since it is to be expected that the ions formed by alpha disintegration from this source will be less advantageously disposed with regard to the central collecting electrode than a majority of the gaseous radon molecules or their disintegration products.

Performance Data

The background count, in consequence, was reduced to 0.4–0.6 counts per minute. The radium solution used for calibration was obtained from the National Bureau of Standards in the form of a sealed pyrex ampule containing 50 micrograms of radium with an estimated uncertainty not exceeding 0.7%. The standard was diluted to convenient concentrations using 2% barium chloride and 5% hydrochloric acid by weight (the diluent used by NBS in the original standard).

Deemanation of the substandard solution provided a sample of radon of known activity. After a background count of one hour or more, the radon sample was introduced into the chamber and counted for a period of four hours.

After introduction of radon into the chamber, the counting rate increases because of the accumulation of the short-lived alpha-emitting disintegration products of radon as illustrated by the following diagram:

$$\text{Ra (1,590 y)} \xrightarrow{\alpha} \text{Rn (3.82 d)} \xrightarrow{\alpha}$$
$$\text{RaA (3.05 m)} \xrightarrow{\alpha} \text{RaB (26.8 m)} \xrightarrow{\beta^-}$$
$$\text{RaC (19.7 m)} \xrightarrow{\beta^-} \text{RaC' (150 } \mu\text{sec)} \xrightarrow{\alpha} \text{RaD (22 y)}$$

Since the count per $\mu\mu$c Rn per minute increases until a transient equilibrium is attained at 3 hours, average calibration figures were calculated for each hour after introduction of the sample. This calibration figure is expressed in terms of net cpm/$\mu\mu$c.

Table 1 contains calibration data from 5 determinations on each of 2 independent chamber and amplifier combinations available for the radium measurements. It will be noted that

the 5 comparable values show the satisfactory agreement of calibration factors applicable to each of the 4 successive hourly periods. In the calculation of the activity of an unknown radon sample, the average number of net counts per minute for the first, second, third, and fourth hours are divided by the appropriate calibration value. These 4 determinations are averaged to give the activity of the radon unknown in $\mu\mu c$ at the time of measurement. This calibration procedure permits the sample to be counted immediately after introduction into the chamber.

Control Experiments

A number of possible sources of error in connection with the method of radium analysis outlined were investigated experimentally with a view toward improving the method where possible, or failing that, establishing the necessary correction factors. The results of these studies are detailed below:

Possible errors connected with ashing procedures:

(*a*) After completing the analysis of the first 5 bodies, which were ashed on the floor of the crematory, the possibility of contamination of the body ashes by loose mortar and particles of firebrick was suspected and subsequent ashing was performed with the bodies placed on the stainless steel plate as described previously. To evaluate the order of contamination likely under the earlier conditions, a radium determination was made of a sample of firebrick and cement from the furnace. Approximately 10 gm of this material were ground to a powder and mixed, and a 1-gm aliquot was chemically digested and measured in the manner described above. The analysis indicated 5.2×10^{-12} gm radium per gm firebrick. As will be described later, this value for radium concentration in firebrick is about 100 times the average radium concentration in bone ash. The question of contamination in the furnace is, therefore, a matter of concern when ashing is done on the crematory bed.

(*b*) Loss of radium by volatilization during the ashing process was investigated as follows: A sample of fresh bone, consisting of two each of tibia, fibula, and femur bones, was cleaned by scraping, and then crushed; the fat was extracted with an alcohol-ether mixture in a Soxlet extractor. Subsequently the dry fat extracted bone was ground to a fine powder (60 mesh) in a Wiley Mill. The resulting sample was thoroughly mixed, and 7 aliquots of 27 gm each were weighed out. Sample #1 was set aside and the other 6 samples were heated for two hours at selected temperatures covering a range from 400° C to 1000° C in a temperature-regulated muffle furnace. Each of the 7 samples was then digested, deemanated, and measured in the usual manner. Table 2 lists the results obtained and indicates that there was no significant loss of radium during ashing. This confirms the earlier observation by Evans (*4*).

Possible errors in chemical digestion processes:

(*a*) To control the possibility of radium contamination by reagents used

TABLE 2
Effect of Ashing Temperature on Radium Recovery

Sample No.	*Ashing Temperature*	*Ra in 27 gm dry fat extracted bone* 1×10^{-12} *gm Ra*
1	not ashed	0.49 ± 0.04
2	400° C	0.53 ± 0.03
3	500° C	0.46 ± 0.04
4	650° C	0.46 ± 0.02
5	800° C	0.35 ± 0.03
6	900° C	0.54 ± 0.03
7	1000° C	0.45 ± 0.03

for digestion of the ash, a blank consisting of double portions of the chemicals used was treated according to the usual routine. The radium measurement corrected to a single portion was $0.02 \pm 0.02 \times 10^{-12}$ gm radium per blank. It was concluded that no significant amounts of radium were incorporated in the ash sample by the digestion agents.

(*b*) Radium recovery was investigated by adding a known amount of radium from a substandard solution to an aliquot from a sample of bone ash on which a radium analysis had been performed. In 5 samples so prepared, the added radium ranged from 2 to 10 times the radium measured in the average bone ash sample. The 5 samples were digested according to the usual procedures, and radium measurements were made. The per cent recovery varied from 64 to 76 with an average value of $72 \pm 0.2\%$. The recovery factor was used to correct all the radium measurements reported in this paper.

RESULTS

Table 3 lists the results obtained on the 25 adult bodies analyzed for radium content. The total body ash was routinely weighed after cremation, and the weight appears in the second column of the table. An exception exists in the listed total ash weights for subjects 3, 4, and 5 since these values are estimates rather than actual weights. The third column lists the weight of the aliquot used for digestion. Several radon samples were collected from each digestion mixture and separately analyzed. The number of analyses performed are listed in the fourth column. The number of micro-microcuries of radon counted are reported in the fifth column.

The calculated number of grams of radium per whole body is listed in the sixth column. These values are weighted averages of the several independent analyses of each sample and have an attached standard error listed in the seventh column. This error pertains only to the measurement of the activity and does not include errors in the preparation of the radium solution. The last column lists the radium content per gm ash.

The radium content of the 25 bodies analyzed is found to vary from 0.38 to 4.30×10^{-10} gm radium with an average value of 1.59×10^{-10} gm radium. The first 5 values listed in the table are in general high and, as discussed under "Method," may well be erroneously large because of contamination of the ash sample by radium-containing particles of firebrick and mortar. If the first 5 values are excluded on this ground, an average radium body content of 1.18×10^{-10} gm radium is obtained. The latter value is used for the comparisons made below in the discussion.

Since the subjects of this study are presumed to have had no occupational exposure to radium, it is pertinent to list the occupations for the individuals for which this information is available. These data, together with age, sex, birthplace, and years' residence in New York State, are presented in Table 4.

Table 5 lists the results obtained by radium analyses of the bodies of 6 stillborn infants. It is noteworthy that the average concentration of radium in the ash is 0.36×10^{-12} gm radium per gm ash for the infant carcasses and 0.50×10^{-13} gm radium per gm ash for the adult bodies.

DISCUSSION

The most striking finding of this investigation is that the average value arrived at for radium body content is about 100 times smaller than the average value reported by Krebs. This discrepancy may be related to the difference in the geographical location from which the respective samples are

TABLE 3

Measurements of Body Radium Content of Individuals with No Known Exposure

Body No.	Measurements				Body Radium Content		
	Total ash (gm)	Aliquot (gm)	No. of meas.	Avg. μμc radon	10^{-10} gm Ra per total ash		10^{-12} gm Ra per gm ash
					Values	Standard error	
1	2,580	25.8	1	3.00	4.30	±0.30	1.67
2	2,500	20.0	3	1.39	2.74	±0.08	1.10
3	2,500	20.3	2	0.94	1.70	±0.08	0.68
4	2,500	25.0	2	1.96	3.48	±0.14	1.39
5	3,350	33.5	2	2.41	4.00	±0.08	1.19
6	4,410	22.0	2	1.17	3.53	±0.21	0.80
7	1,500	15.0	2	1.06	1.35	±0.09	0.90
8	2,500	20.0	3	0.52	1.01	±0.05	0.40
9	2,100	21.0	3	0.88	1.44	±0.06	0.69
10	1,700	20.0	3	0.48	0.56	±0.04	0.33
11	2,000	20.0	3	0.49	0.64	±0.05	0.32
12	2,200	20.0	3	0.44	0.65	±0.05	0.30
13	790	20.0	3	0.68	0.42	±0.02	0.53
14	2,480	20.0	3	0.46	0.96	±0.07	0.39
15	2,260	20.0	3	0.57	1.01	±0.06	0.45
16	1,570	20.0	3	0.91	0.99	±0.05	0.64
17	1,970	20.0	3	0.51	0.75	±0.05	0.38
18	2,570	20.0	3	0.42	0.65	±0.07	0.25
19	2,000	20.0	2	0.42	0.38	±0.09	0.19
20	2,310	20.0	3	0.50	0.61	±0.05	0.26
21	2,500	20.0	3	1.17	2.08	±0.07	0.83
22	3,190	20.0	3	0.96	2.26	±0.08	0.71
23	3,520	20.0	2	0.86	1.94	±0.11	0.55
24	1,780	20.0	3	0.89	1.04	±0.09	0.58
25	2,970	20.0	2	0.70	1.30	±0.08	0.44
Avg. of all values	2,390	20.9	2.7	0.95	1.59	±0.23	0.64
Avg. of Nos. 6–25	2,316	19.9	2.8	0.74	1.18	±0.14	0.50

drawn or it may be associated with the technical difficulties in the analysis.

Is the Rochester sample generally representative?

The geographical location is an important factor in radium uptake by the body since the radium content of the ingested water and, to an extent, of the food probably varies more or less from point to point.

As a consequence of this relation, the areas of residence represented by the subjects who comprised the sample may determine the degree to which the

TABLE 4

Biographical Data on Individuals Whose Bodies Were Studied for Radium Content

Body No.	*Age*	*Sex*	*Birthplace*	*Residence (years)*	*Occupation*
1	82	M	Corning, N. Y.	60—N. Y. S.*	Printer
2	55	M	Plainsfield, Vt.	Unknown	Cook
3	68	M	Austria	Unknown	Itinerant
4	54	M	Canada	Unknown	Laborer
5	65	M	Rochester, N. Y.	65—Rochester, N. Y.	Odd jobs
6	48	M	Anderson, S. C.	3—Rochester, N. Y.	Odd jobs
7	85	F	U. S. A.	43—Rochester, N. Y.	None
8	60	M	Unknown	Unknown	Itinerant
9	57	M	Unknown	Unknown	Unknown
10	77	M	Rochester, N. Y.	77—N. Y. S.	Carpenter
11	76	M	England	26—England 50—Rochester, N. Y.	Home decorator
12	83	M	Pennsylvania	Unknown	Unknown
13	77	F	U. S. A.	32—N. Y. S.	Housework
14	36	M	Troy, Ala.	10—Rochester, N. Y.	Odd jobs
15	74	M	Cedar Hill, N. Y.	25—Rochester, N. Y.	Marble cutter
16	81	M	Mechanicsville, N. Y.	14—Troy, N. Y. 19—Rochester, N. Y.	Laborer
17	66	M	Buffalo, N. Y.	44—N. Y. S.	Machinist
18	85	M	Unknown	Unknown	Unknown
19	75	M	Toronto, Canada	18—Toronto 50—N. Y. S.	Carpenter
20	74	M	Germany	9—Germany 35—N. Y. S.	Laborer
21	57	M	New York, N. Y.	9—N. Y. S.	Ash collector
22	33	M	Alabama	9—Florida 8—Rochester, N. Y.	Laborer
23	67	M	North Carolina	23—N. Y. S.	Laborer
24	81	M	New York	81—N. Y. S.	Sander
25	54	M	Indiana	8—N. Y. S.	Laborer, Miner

*"N. Y. S." designates New York State.

results may be regarded as representative of the population as a whole. Such pertinent information as could be obtained describing the residential history of each subject has been listed in Table 4.

With regard to place of birth it is seen that 7 states including New York, as well as 4 foreign countries, are represented. In only 2 cases was the subject known to have been born in Rochester, New York. To the extent to which this incomplete information permits characterization of the sample, it may be said with regard to place of birth and either presumptive or verified residence during early years of life, the sample is heterogeneous. On the other hand, 12 subjects of the group spent 25 years or more in continuous residence in New York State preceding their death.

The analytical results may be divided into 2 groups according to either of the 2 criteria mentioned. It may be asked if members of a group known to have

TABLE 5

Radium Content of the Body of Stillborn Infants

Body No.	*Sex*	*Age in months (estimate)*	*Total ash (gm)*	*Aliquot (gm)*	10^{-12} *c Rn measured Avg. of 2*	10^{-12} *gm Ra per infant*	10^{-12} *gm Ra per gm ash*
51	M	7	32.7	20.0	0.44	0.59 ± 0.05	0.30
52	F	7	34.3	20.0	0.36	0.59 ± 0.05	0.30
53	M	4	15.0	15.0	0.48	0.54 ± 0.02	0.36
54	F	4	14.8	14.8	0.62	0.70 ± 0.03	0.47
55	F	3	15.8	15.8	0.46	0.55 ± 0.04	0.35
56		3	15.2	15.2	0.45	0.54 ± 0.03	0.36
Average			21.3	16.8	0.47	0.59 ± 0.02	0.36

been born in New York State differ in regard to total radium content or radium concentration per gm ash from the group known to have been born in places other than New York State. The average whole body radium content for the group born in New York State is 1.07×10^{-10} gm compared with 1.35×10^{-10} gm for the group born outside the state. The comparable figures for radium concentration per gm ash are 0.53×10^{-12} gm and 0.44×10^{-12} gm, respectively. It is concluded that this grouping based on birthplace does not reveal any significant differences in radium content.

A second comparison may be made by dividing the total sample into the group of individuals known to have spent the last 25 years of their life in New York State and another group including the remainder of the subjects. The average body contents for these two groups are, respectively, 0.77×10^{-10} gm radium and 1.58×10^{-10} gm radium. While at first glance this difference would appear to be significant of a lower radium uptake for the 25 years in New York State residents, the average concentrations turn out to be 0.46×10^{-12} and 0.54×10^{-12} gm radium per gm ash, a much less striking and very questionably significant difference.

With reservations necessary because of the small sample, it may be tentatively concluded that no consistent local geographical trend is exhibited by the data. Since it would certainly be expected that the amount of radium taken up by the body would be related to the radium concentrations in the

TABLE 6

Radium Content of Tap Water in Public Water Supplies

*Locality**	*Radium content* 1×10^{-15} *gm/ml water*
Rochester, N. Y.	
Ontario supply	0.062
Hemlock supply	0.013
"	0.078
"	0.080
New York City	0.46
"	2.53
"	0.49
Naturita, Col.	0.87
Uravan, Col.	2.81
Grand Junction, Col.	1.55
Oak Ridge, Tenn.	0.30
"	0.29
"	0.30

* Information on all waters, except Rochester, is due to M. Eisenbud (6).

local water supplies, the interpretation may be made that the radium level in the water supplies of New York State is not greatly different from that in other parts of the country represented by the present sample. An experimental investigation of the radium content of public water supplies of other geographical areas is planned.

The Rochester, N. Y. water supply is derived from two independent sources, Lake Ontario and Hemlock lake, which is a small inland body of water not connected with the Great Lakes system. Preliminary analyses for radium content of tap water from these two supply sources are presented in Table 6, together with measurements of tap water from other regions.

The values for tap water may be compared with the measurements made by Evans, Kip, and Moberg (*5*) on water from the Pacific and Atlantic oceans. These authors find values of from 0.0 to 3.2×10^{-16} gm radium per ml with an average value of 0.8×10^{-16} gm radium per ml water.*

Radium concentration by living organisms. Evans and co-workers (*5*) also measured the radium content of two forms of marine life, i.e., kelp and plankton, and concluded that the radium concentration was about 100 times that of the sea water in which they lived. A similar calculation may be made for the human skeleton. If it is assumed that the wet weight of the bone is about three times the ash weight, the average total wet-bone weight is about 7,000 gm for the human subjects studied. The radium concentration in wet bone may, therefore, be calculated as 1.7×10^{-14} gm radium per gm wet bone. Assuming an average water value of 0.6×10^{-16} gm radium per ml, a concentration factor of about 280 times is obtained.

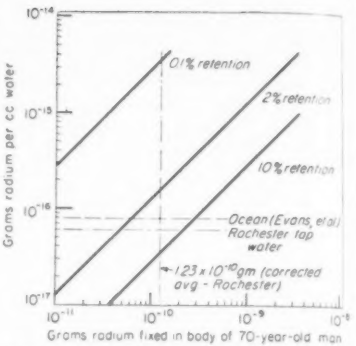
Grams radium per cc water
Grams radium fixed in body of 70-year-old man
0.1% retention
2% retention
10% retention
Ocean (Evans, et al)
Rochester tap water
1.23 x 10⁻¹⁰ gm (corrected avg - Rochester)

FIG. 4. Relation between radium content of water ingested and predicted body content assuming excretion is a constant per cent (0.005) of the radium retained

Estimation of radium body content on a basis of radium content of water supplies. If the radium concentration in the water supply is assumed to have a certain value, the whole-body radium content of a man 70 years old may be calculated by making use of studies of human radium metabolism as reported in the literature. A summary of such information is contained in a review article by Silberstein (*8*).

Directly after radium ingestion, relatively large amounts are excreted in the feces and urine. The radium, rapidly mobilized from the soft tissues, is being laid down in the bone so that within a few weeks after a single does, the skeleton contains almost the entire body content of radium. Over a period of months and years, the rate of excretion in terms of per cent body content becomes progressively less as the bone-deposited radium becomes less available to the circulating blood. At

* Hevesy and Paneth (7) quote radium content of sea water as averaging between 10^{-15} and 10^{-16} gm per ml, and report that the radium content of large rivers is of the same order of magnitude as the sea water. These authors further note that the thermal springs at Gastein, Germany, contain 10^{-12} gm radium per ml. The high values obtained by Krebs might be accounted for if his subjects came from that part of Saxony noted for its radioactive spas.

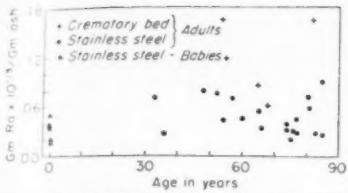

FIG. 5. Relation between age and radium concentration in body ash

length, after about two years, the radium is excreted at so slow a rate that the remaining body content may, for convenience, be referred to as the "permanently" retained radium. Measurements of this quantity range from 0.1 to 10% of the original dose with an average value of 2%. At the time when this condition of relative stability is attained, the amount of radium excreted per day is found to equal a constant factor, 5×10^{-5} times the total amount of radium in the body at the time of measurement.

Making use of these constants and making the further assumptions that a 70-year-old human has been ingesting 2.5 liters of water per day (including water as liquid and as contained in food) for the whole of his lifetime, an approximate value for the radium content of his body can be arrived at. Such calculations have been made for an appropriate range of radium concentrations and for radium retentions of 0.1, 2.0, and 10% of the dose.

Figure 4 shows the predicted radium body contents. The vertical dotted line represents the average radium content of subjects Nos. 6 through 25.* It will be seen that the average value for Rochester tap water, 0.62×10^{-16} gm radium per ml, is somewhat lower than the radium water concentration of 1.6×10^{-16} gm radium per ml which would be predicted from body ash measurements and the assumptions of an average 2% radium retention.

This disagreement is not regarded as serious. On the contrary, in view of the uncertainty of some of the biological factors, it is surprising that the experimental findings fit so well with the currently accepted constants for radium metabolism and the expected range in radium content of public water supplies.

Radium content versus age of the subject. The present understanding of radium metabolism would predict that radium body content increases with the age of the subject. Since it is reasonable to expect that the total radium of the body would also be proportional to total body size or bone weight, the concentration of radium in gm radium per gm ash has been plotted against the age of each subject in Fig. 5.

The graph does not provide any evidence for the expected increase in radium concentration with increase in age. Perhaps this is not surprising in view of the smallness of the sample, the lack of values in the younger age range, and the experimentally verified difference in radium retention among individuals of the same age.

It is interesting to note that the stillborn infants have an appreciable concentration of radium in their body ash. Our experimental data do not reveal whether this radium is confined to the forming bone or exists in the soft tissues as well. The rather high level may indicate that, under conditions of rapid bone growth, the "permanent" retention of radium is greater than that determined for adult individuals and that, therefore, the major proportion of the radium does, in fact, reside in the developing bone of the infants measured.

Radium as an etiological factor in osteogenic sarcoma. The present find-

* Since the average age of subjects Nos. 6 through 25 is 67 years, a small correction factor has been applied to bring the average radium body content up to 70 years.

ing of an average body content of about 1×10^{-10} gm radium in individuals not occupationally exposed to radium makes it appear unlikely that radiation from this source is an important etiological factor in osteogenic sarcomas of unknown origin.

To the extent to which the present value is representative of the population as a whole, the safety factor is increased about 100 times by comparison with that based on the formerly published values for the radium content of the body. The comparison of radium levels known to produce neoplastic bone changes and levels existing in occupationally unexposed individuals becomes as 5×10^{-8} gm is to 1×10^{-10} gm or about 50,000 to 1.

The average radiation in rep (roentgen equivalent, physical) may be calculated for a 70-kilo man with 1×10^{-10} gm of radium equally distributed throughout 7,000 gm of wet bone. It will be assumed that about 45% of the radon formed is lost in the breath and the rep will be taken as the dose received when the bone absorbs 93 ergs of energy per gm. The calculation shows that the alpha radiation dose to the bone is 1.13×10^{-5} rep per day.* The maximum permissible dose for long-term exposure to alpha radiation by internal emitters is about 2.2×10^{-3} rep per day.†

The assumption that radium is distributed equally throughout the skeletal mass may be somewhat questionable but, on the other hand, the calculated dose from radium is about 200 times smaller than the presently recognized maximum safe level. Therefore, this type of calculation may also be regarded as an indication that radium in the body of the normal individual is very unlikely to lead to the development of osteogenic sarcomas.

It may be noted that although the above conclusions may be valid for the general population, the argument does not exclude the possibility of high radium contamination of some local water supplies, a correspondingly high radium uptake, and the production of osteogenic sarcomas.

Under such circumstances, the radium concentration of the water would probably have to be of the order of 1×10^{-13} gm radium per ml water. As mentioned, the thermal springs at Gastein, Germany, do, in fact, contain such a level of radium. It is believed, however, that few such regions exist and that, therefore, body radium as an etiological factor in bone neoplasms is a likelihood only in a relatively small number of geographical locations.

SUMMARY

The radium content of the body of 25 adult individuals with no known occupational exposure to radium has been measured. The range of values is from 0.38 to 4.3×10^{-10} gm radium with an average value of 1.50×10^{-10} gm radium. Because of possible experimental contamination of five ash samples, a better average value is believed to be 1.18×10^{-10} gm radium per whole body. The corresponding value for the concentration of radium in the ash is 0.50×10^{-13} gm radium per gm ash. The average age of the adult subjects was 67 years.

The body ash of six stillborn infants was found to contain an average of 0.32×10^{-13} gm radium per gm ash.

The above radium values for adult bodies agree qualitatively with predictions based on the radium content of the water supply and known constants for radium metabolism by the body. The radium content of the body, as derived from measurements

* This includes only the alpha radiation from radium and its daughter products. Some additional alpha radiation might be expected from the decay products of mesothorium.

† This value assumes a 0.3 rep per week for beta MPD, reduction by a factor of 20 for greater specific ionization of alpha particles, a 24-hour day and 7-day week.

reported in this paper, is about 100 times lower than analogous figures previously existing in the literature and about 50,000 times lower than radium content known to produce neoplastic bone changes. It is, therefore, concluded that to the extent to which the present measurements are representative, it is unlikely that irradiation of the bone by body radium will be an important factor in the production of osteogenic sarcoma in individuals not occupationally exposed to radium.

* * *

The authors wish to acknowledge the kind cooperation of Prof. C. E. Tobin of the Anatomy Department of Strong Memorial Hospital, Rochester, New York, who made available to us the human material and the facilities of the crematorium for our investigation.

BIBLIOGRAPHY

1. Adolf Krebs, *Strahlentherapie* **72,** 164 (1942)
2. J. C. Aub, H. S. Martland, R. D. Evans, quoted by H. Silberstein in reference 8
3. W. B. Lewis, "Electrical Counting" (The Macmillan Co., New York, 1943)
4. R. D. Evans, *Rev. Sci. Instr.* **6,** 99 (1935)
5. R. D. Evans, Arthur F. Kip, E. G. Moberg, *Am. J. Sci.* **36,** 241, 5th series (1938)
6. M. Eisenbud, AEC, New York Operations Office, personal communication of Feb. 23, 1950
7. G. Hevesy, F. A. Paneth, "A Manual of Radioactivity" (Oxford University Press, London, 1938)
8. H. E. Silberstein, AECD 2122 (1945)

Use of the Pile for Chemical Analysis (*Continued from page 17*)

great sensitivity is needed or rapid analysis is required.

For one practical application of the nuclear method, consider the difficulty of quantitatively determining the per cent hafnium in zirconium by chemical means. This is an almost insoluble problem, one which cannot be done without much labor. With a one-minute bombardment of 10 mg of Hf-Zr oxide in a neutron flux of 10^{11}, as little as 10 ppm of Hf may be detected with a Geiger counter via the 27 sec (mean life) isomeric transition in one of the odd isotopes of hafnium.

To sum up, then: In a neutron radiation laboratory, chemical identification may be effected by activation (β^-, e^-, β^+, γ, X), thermal and resonance neutron scattering and absorption, and by other special means. These methods are rapid and highly sensitive, but in general should be reserved for difficult two component cases.

* * *

The authors wish to express their indebtedness to Professor M. Goldhaber for his many contributions to this work during his 1946-1948 association with Argonne National Laboratory.

BIBLIOGRAPHY

1. G. T. Seaborg, I. Perlman. Table of Isotopes, *Revs. Mod. Phys.* **20,** 585–667 (1948)
2. L. Seren, H. N. Friedlander, S. H. Turkel. Neutron Activation Cross Sections, *Phys. Rev.* **72,** 888 (1947)
3. K. Way, G. Haines. Thermal Neutron Cross Section Compilation, U. S. Atomic Energy Commission AECD-2138
4. H. H. Goldsmith, H. W. Ibser, B. T. Feld. Neutron Cross Section Compilation, *Revs. Mod. Phys.* **19,** 259–297 (1947)
5. T. I. Taylor, W. W. Havens, Jr. Neutron spectroscopy for Chemical Analysis—I, II, III, NUCLEONICS **5,** No. 6, 4 (1949); *ibid.* **6,** No. 2, 66 (1950); *ibid.* **6,** No. 4, 54 (1950)
6. A. H. Compton, S. K. Allison, "X-rays in Theory and Experiment" (D. Van Nostrand Company, Inc., New York, 1935)
7. A. Wattenberg. Photoneutron Sources, *Phys. Rev.* **71,** 497 (1947)
8. D. J. Hughes, W. D. B. Spatz, N. Goldstein. Capture Cross Sections for Fast Neutrons, *Phys. Rev.* **75,** 1781 (1949)

A Direct Method for

Determining Radium in Exposed Humans

Radium in urine and other biological materials can be routinely determined by a rapid, sensitive method involving counting of alpha particles from the radium, following separation. Newly devised, it is described here step by step

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INCORPORATION of radium in the body constitutes a real health hazard as shown by the many fatal and crippling incidents reported in the literature (*1*).

In the form of Ra^{226}, it is widely used in varied industries, medicine, and scientific investigations. Many applications utilize the radium in sealed capsules, but where it is exposed, such as in the commercial extraction of radium, manufacture of radium dials, and metabolic investigations, the accidental entrance of radium into the body is a major concern. Therefore, the amount of radium that may have accumulated in the body of a suspect individual should be rapidly and accurately determined.

The usual procedure for evaluating body content of radium consists of measuring the radon content of the expired air (*2*), but this method is time consuming and requires special apparatus and techniques. It would be preferable and more convenient to analyze the urine for radium directly. This can be done by the techniques used in radon measurement, or by the relatively insensitive procedure of measuring the beta activity of the decay products under controlled conditions (*3*). Both methods are unsuited for routine and repeated determinations on large numbers of individuals.

A preferred method is one involving the direct counting of the alpha particles from radium itself, provided that the radium can be separated from large amounts of material. This has been accomplished by the authors by adapting a procedure devised by Ames *et al.* (*4*) for the assay of radium in uranium process solutions. This method adequately meets the sensitivity and accuracy required for routine analysis of Ra^{226} in excreta. The latter point is discussed more fully following the description of the analytical procedures.

In outline, the method consists of wet-ashing urine or tissues with concentrated nitric acid, dissolving the ash in 0.1*M* HNO_3, and coprecipitating the radium with lead sulfate; the lead sulfate precipitate is dissolved in HCl and the radium coprecipitated with a few milligrams of $BaCl_2$. The radium containing $BaCl_2$ precipitate is deposited on a platinum or glass disc and treated with H_2SO_4 to give a uniform-adhering deposit. The sample is then counted in a proportional or parallel-plate pulse chamber.

An alternative step for removing interfering anions involves the use of a cation exchanger to adsorb the radium from the ashed solution, and subsequent elution of the radium with HNO_3. The

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addition of the ion exchange step will find use in solutions that have an excess of interfering anions or cations.

Experimental Procedures and Results

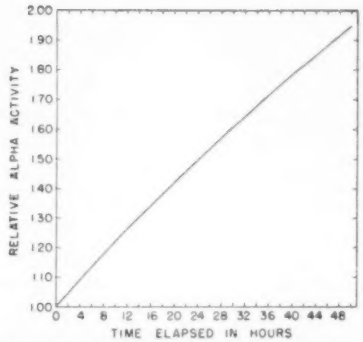
A description of the assay of radium in a 24-hour sample of urine is given in Table 1. The reagents (chemical pure) required are as follows:

1. Nitric acid, concentrated and dilute (0.1*M*).
2. Lead carrier, 200 mg per ml (as Pb); 32 grams of $Pb(NO_3)_2$ are diluted to 100 ml.
3. Barium carrier, 10 mg (as Ba); 1.9 grams of $Ba(NO_3)_2$ are diluted to 100 ml.
4. Sulfuric acid concentrated, and dilute (0.5*M*).
5. HCl-ether reagent which consists of six parts, by volume, of concentrated HCl and one part of ethyl ether.

At least 40 separate analyses by three different analysts were made by the method given in Table 1. Samples of urine were spiked with Ra^{226} (in some cases Ra^{228}), tracers varying from 3 disintegrations per minute (1.4×10^{-12} gm) to 3500 dpm (1.5×10^{-9} gm). Consistent recoveries of 98 ± 1% were obtained.

One analyst can run twelve or more samples a day. With the permissible levels of Ra^{226} that may be present in the urine, as discussed later, one low background alpha counter (Table 1) is sufficient for the job.

Correction for the growth of Ra^{226} and its decay products can be made from the growth curve shown on this page. Six samples counted at near equilibrium, more than three weeks after mounting, had increased in activity 4.0 ± 0.2 times the activity at zero time.* This result indicates that, for practical purposes, all the radon



Growth of alpha activity of Ra^{226} samples mounted on discs, as described in Table 1. Zero time was taken as the time at which the disc was flamed. Only one curve was drawn because the experimental data checked the theoretical curve. The theoretical curve, assuming no loss of radon, was calculated from the expression $F = 1 + 3\ (1 - e^{-\lambda t})$, where F is the relative activity and λ the disintegration constant = 0.00755 hour^{-1} for Rn^{222} ($T_{1/2}$ = 3.825 days)

released by the deposit was retained since each disintegration of radium gives rise to four alpha particles, namely radium, radon, RaA, and RaC. The tenacious retention of Rn by $BaSO_4$ is well known (*5*).

Ames *et al.* (*4*) have studied the separation of alpha contaminants from radium by the $PbSO_4$-$BaCl_2$ precipitation procedure. They show that good separation is obtained from the isotopes of uranium, thorium, polonium, bismuth and protactinium. Actinium is decontaminated by a factor of 10–20.

The effects of varying the amounts of Pb carrier were studied for the conditions given in Table 1. With 40 or more mg of added Pb, the carrying of Ra is nearly quantitative. As little as 20 mg of added Pb carried about 85% of the Ra.

Inasmuch as calcium is a common and variable constituent of excreta, the recovery of Ra in the presence of various amounts of Ca was determined. A daily urine or fecal sample contains

* Zero time is taken as the time at which the disc is flamed following the deposition of the $BaCl_2$ precipitate.

TABLE 1

Directions for Analyzing Radium-226 in a 24-Hour Urine Sample

Sample. Add 100 ml of concentrated HNO_3 and evaporate to dryness on a hot plate. Cool, and add about 20 ml additional HNO_3 and evaporate again. Repeat until a white ash is obtained (Notes 1, 2). Add 150 ml of 0.1*M* HNO_3, warm for 5 minutes, transfer solution to a 250-ml centrifuge bottle. Centrifuge and transfer supernatant to a second 250-ml centrifuge bottle. Rinse beaker with 50 ml of 0.1*M* HNO_3, use washings to wash precipitate in first centrifuge bottle. Centrifuge and combine both supernatants. To the combined supernatants add dropwise, while stirring mechanically (Note 3) with a platinum wire, 3 ml of concentrated H_2SO_4 followed by dropwise addition of 0.50 ml of lead carrier. Immerse the bottle in a bath of ice water and continue stirring for 15 minutes. Centrifuge. Discard solution.

Precipitate. $PbSO_4$ plus Ra^{226}. Dissolve by gently warming with 15 ml of HCl-ether reagent. Transfer solution quantitatively to a 50-ml centrifuge tube using a total of 10 ml of HCl-ether reagent for washing. Cool tube in ice bath. Add 0.40 ml of barium carrier while stirring. Continue to stir for 5 minutes. (Note 4.) Centrifuge in ice-packed cups for 5 minutes. Discard solution.

Precipitate. $BaCl_2$ plus Ra^{226}. Add 1 ml of 0.1–1*M* HNO_3, expedite solution of precipitate by disintegrating precipitate with a platinum rod, transfer slurry with a capillary pipet to a platinum plate ringed with Zapon lacquer (Note 5), evaporate under infra-red lamp for 2–3 minutes, add 4 drops of 0.5*M* H_2SO_4 and evaporate to dryness (Note 6). Flame the plate carefully over a small flame to burn off lacquer border; then flame to red heat over a Meker burner. Count the deposit in a parallel-plate alpha counter (Note 7).

NOTES:

1. The time required for ashing requires 4–6 hours. Subsequent steps take less than an hour. The ashing procedure insures complete removal of radon, and allows time for the decay of the short-lived alpha-daughter activities.

2. Feces may be wet ashed by modifying the procedures as follows: Dry the feces at 80°–100° C overnight, place in muffle furnace and heat at 450°–500° C for an additional 24 hours. Then ash residue with HNO_3, as described for urine.

3. A satisfactory smooth running stirrer is sold by Palo Myers, Inc., New York, Model 7605.

4. The conditions for precipitation of barium with the HCl-ether reagent are based on those developed by Hume, Ballou, and Glendenin (*12*).

5. The platinum plates are about 4 cm in diameter. The approximate diameter of the deposited sample is 3.5 cm. The Zapon lacquer is applied in a margin 2–4 mm wide around the edge of the disc. When dry, it prevents the solution from running off. The platinum discs are re-used after removing the radium deposit. This is done by heating the discs overnight or longer in fuming sulfuric acid which forms a soluble sulfate complex by reaction with $RaSO_4$. Glass plates about 4 cm in diameter and 2–3 mm thick have been used routinely (*4*) and have the advantage that they may be discarded after each analysis. They may be purchased from the Scientific Glass Apparatus Co. The Zapon lacquer is made by the Zapon Division, Atlas Powder Company, North Chicago, Illinois. The lacquer is thinned with a small amount of acetone before use.

6. The residue as prepared for direct counting is uniform and adhering. Previous attempts to develop a direct count method with $BaCl_2$ but without the addition of H_2SO_4 for use with tissues (*5*) were unsatisfactory, largely because of splattering and of the formation of irregular deposits.

7. The alpha counter used gave a background of less than 2 counts an hour with a counting efficiency of about 50%. For the sensitivity and accuracy required in ordinary work, practically any commercially available alpha counter is satisfactory. However, it should be noted that many of the alpha counters available require an undue amount of servicing.

about 0.2 and 0.4 gm of Ca, respectively. We find that about 0.3 gm of Ca does not interfere with the carrying of Ra by 50 mg of Pb carrier.

By increasing the amount of Pb carrier to 100 mg and doubling the volume from which the precipitation is made (200 ml), it is possible to recover Ra completely from 200 ml of a solution containing 1 gm of Ca. The method can be extended to higher ranges but more Ba would be needed to carry the radium from the dissolved $PbSO_4$ solution.

The self-absorption losses of radium alpha particles can be determined empirically. Under the conditions of mounting and counting reported here, the self-absorption losses are less than 3%. A 4-mg deposit of $BaCl_2$ amounts to an absorption equivalent of 0.4 mg per cm² since it is spread over an area of about 10 cm².

Optional Cation Exchange Step

The use of a cation exchange resin for isolating radioelements from urine was described in a previous publication (*6*). In the present work, an ion exchange step may find application for cases where the type and amounts of interfering anions would interfere with the coprecipitation steps. Recently, a cation exchange resin was employed as an aid in determining barium, strontium, and the rare earths in urine by separating out the interfering phosphates (*7*).

It is possible to use the ion exchange method for separating the radium from large amounts of other cations. For example, the adsorption affinity of Ra^{++} is so much greater than that of

TABLE 2

Directions for Isolating Radium from Urine—Cation Exchange Step

Sample. Urine (24-hour sample). Wet ash (Note 1) with nitric acid as described in Table 1 and dissolve ash in HNO_3 as before. Centrifuge away any insoluble material and discard after washing.

Solution. Volume is about 100 ml, dilute to 150 ml with H_2O. Place in 250-ml glass-stoppered Erlenmeyer flash containing 2 grams of air-dried hydrogen or sodium form of Dowex 50 (100–150 mesh). Shake flask for 1 hour. Remove and discard supernatant solution. Treat with additional 1 gram of resin. Shake flask for 1 hour; then discard the supernatant.

Combined resin. Contains >95% of original radium. Wash with 80 ml 0.02*M* HNO_3. Add 50 ml of 8*M* nitric acid (Note 2) and digest resin while stirring for 30 minutes in oil bath kept at 90–110° C. When resin settles, decant supernatant into 250-ml beaker. Add 50 ml more or 8*M* HNO_3 and repeat digestion step. Combine supernatants and discard resin.

Supernatants. Ra^{226} in HNO_3. Evaporate to near dryness. Transfer quantitatively to a 25-ml centrifuge tube keeping total volume to 15 ml. Coprecipitate Ra with $PbSO_4$ as given in Table 1, except use 0.5 ml concentrated H_2SO_4 and 0.1 ml of Pb carrier for first step.

NOTES:

1. The resin will carry the Ra from fresh urine. In one case, 100 ml of urine was acidified with 1 ml of concentrated HNO_3 and shaken for one hour with two grams of resin. Undoubtedly larger volumes of urine can be treated directly for Ra separation by using more suitable acid concentrations and appropriate amounts of resin.

2. The use of 8*M* nitric is quite important for the elution step. Weaker or stronger concentrations of HNO_3 give incomplete elution. In the former case, this is probably due to insufficient H^+, while, in the latter, the acid reacts with the resin, which not only results in increasing the sulfate content of the solution, but causes a large part of the adsorbed radium to be held irreversibly. The increased sulfate comes from sulfonic acid groups in the resin.

Ca^{++}, while the citrate complex of Ca^{++} $(CaCit)^-$ is so much weaker than the corresponding radium complex ion,* that a suitable adjustment of the *p*H will result in a nearly complete adsorption of Ra while the major fraction of the calcium remains in solution.

The conditions for using the cation exchange step are given in detail in Table 2. Many conditions were tested to obtain optimum results:

a) *Rate of adsorption:* Adsorption was rapid and complete in essentially 60 min. The plateau region was nearly attained within 30 min.

b) *Varying weight of exchanger:* According to the equation

$$K_d = \frac{\% \text{ in exchanger}}{\% \text{ in solution}} \times \frac{\text{volume of solution (ml)}}{\text{mass of exchanger (mg)}} = \lambda \times \frac{v}{m}$$

where K_d is the distribution coefficient. If the adsorption is a true exchange, then K_d will remain constant as v/m is changed (*8*). Over a 16-fold range in v/m, it was found that under the conditions given in Table 2, K_d remains practically constant at 0.23 ± 0.04.

Discussion

It is of interest to consider the sensitivity of the method given in Table 1.

If we assume that counter plus a given reagent yields 0.05 counts per minute, then we can place credence in any value that is at least three times background, or a net of 0.1 cpm. This calculation assumes the use of a low background counter (< 0.033 cpm). At a geometry of 50%, this means that one can quantitatively assay for 0.1 micromicrocurie (10^{-13} gm) of Ra^{226} per liter. The sensitivity can be increased further to a maximum factor of 4 by allowing the radium decay products to accumulate.

The permissible level for *permanently fixed* radium in the body is 0.1 $\mu g = 2.2 \times 10^5$ dpm. At six months after exposure, the daily urinary excretion of *absorbed* radium is at least 0.01% of the amount fixed in the body (*9*). This means that an individual with 0.1 μg of Ra^{226} fixed in the body would excrete $2.2 \times 10^5 \times 10^{-4} = 22$ dpm or 11 cpm at 50% geometry. The elimination rate in long-standing chronic radium poisoning (of the order of 10 years) is about 0.0005% per day in the urine (*10*). (The fecal Ra is ten times the urinary). This amounts to 1.1 dpm or 0.55 cpm detectable by the $PbSO_4$-$BaCl_2$ procedure.

An unexposed human has a normal radium content of the order of 10,000 dpm (*11*) so that the given activity in a daily urine sample due to normal radium content is probably of the order of 0.05–0.1 dpm, or 0.2–0.4 dpm at radioactive equilibrium.

* J. Schubert, in paper to be published.

BIBLIOGRAPHY

1. H. S. Martland, "Textbook of Medicine," edit. by R. L. Cecil, pp. 523–527 (W. B. Saunders Co., Philadelphia, Pa., 1943)
2. R. D. Evans, *Am. J. Roentgenol. Radium Therapy* **37,** 368 (1937)
3. P. C. Tompkins, W. P. Norris, L. Wish, R. D. Finkle, "Methods for the quantification of radium," U. S. Atomic Energy Commission MDDC-699 (1946)
4. D. P. Ames, J. Sedlet, A. H. Anderson, T. P. Kohman, in "The Transuranium Elements," NNES IV-14B, paper 22.70, pp. 1700–1716 (McGraw-Hill Book Co., Inc., New York, 1949)
5. O. Hahn, "Applied Radiochemistry," Chapter IX (Cornell University Press, Ithaca, N. Y., 1936)
6. J. Schubert, E. R. Russell, L. B. Farabee, *Science* **109,** 316 (1949)
7. P. C. Tompkins, L. B. Farabee, J. X. Khym, "Procedure for the radiochemical analysis of barium, strontium, and the rare earths in human urine," U. S. Atomic Energy Commission AECD-2692 (1949)
8. J. Schubert, E. E. Conn, NUCLEONICS **4,** No. 6, 2 (1949)
9. H. E. Silberstein, "Radium Poisoning," AECD-2122 (1945)
10. J. C. Aub, R. D. Evans, D. M. Gallagher, D. M. Tibbets, *Ann. Internal Med.* **11,** 1443 (1938)
11. A. V. Grosse, W. F. Libby, *Science* **106,** 88 (1947)
12. D. N. Hume, N. E. Ballou, L. E. Glendenin, to be published in the National Nuclear Energy Series (McGraw-Hill Book Co., Inc.)

Argonne National Laboratory —Relationships with Industry

Argonne is the center of reactor operation for the AEC. Thus it is one of the major points of contact between industry and the AEC. Described here are pertinent aspects of the problems it faces in bringing industry into its program

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ARGONNE NATIONAL LABORATORY operates under a contract with the University of Chicago. This forms a tripartite type of operation in which we have the laboratory, which is an entity in itself, the contractor, who has certain responsibilities and obligations, and the Atomic Energy Commission.

Sometimes we find two of the three members lined up on one side and the third on the other. Occasionally it is the contractor and the laboratory on one side, and the AEC on the other. Sometimes it is the laboratory and the AEC on one side, and the contractor on the other. And there have been occasions in which the contractor and AEC were on one side, and the laboratory on the other. Thus, there is variety in this type of operation.

However, the fact that we are growing steadily indicates that it is a type of operation that can be made to work, and made to work effectively.

Argonne, with a change of name, is one of the heritages from the Manhattan District, which took it over from the OSRD. In February 1942, when the laboratory got its start, the payroll listed a total of about thirty-five names. At the present time the laboratory has about 2,500 people on the payroll. Slightly over 500 of these are technical people with either engineering or scientific degrees of one kind or another. A fair number of these are people in the Ph.D. category—perhaps half of the total number of research people in the laboratory.

Problems of Growth

When the laboratory was first started, most of the work was done by physicists. Within the first few months of operation, however, it was clearly apparent that we were not going to get through with the job without active engineering help. Thus, an engineering division was formed.

Almost at the same time it was apparent also that, if we were going to recover plutonium from our reactors, we were faced with a tremendous chemical task. And so the chemistry division was formed. The chemistry problem is still one of the key problems, from the point of view of recovery of fissionable materials and handling of waste materials.

With recognition of the health problems faced in the laboratory came the

EDITOR'S NOTE: This article was adapted from the transcript of an informal talk given before a meeting of the Industrial Research Institute, Inc., in Rye, New York, on April 27.

formation of the health division, now the biology division.

The metallurgical work grew directly out of our engineering division. The engineering division has more or less ceased to exist as a separate entity, and has been replaced by a metallurgical division. At the present time we find the laboratory organized with a physics division, a chemistry division, a chemical engineering division, and metallurgy and biology divisions, covering the major points of attack on reactor problems.

Reactor Projects

Instead of having the reactor work all in one division, we now set it up as a matter of projects as the AEC approves various reactors for actual construction. These projects are set up to take care of the characteristic problems of reactor operation, design and development. They are carried on usually from some preliminary design for which a feasibility study has been made. To complete that feasibility study we then go on through the phases of design concerned with the reactor core, control mechanisms, stability, shielding, cooling, etc.

It is extremely difficult, however, to separate the operations of one of these divisions from another, and this is one of the basic problems that we face in the matter of dealing with help from the outside. We are still at the point where a reactor is really a research problem and not a matter of a development project.

And we are still far from the point where one can guarantee the results before one starts the actual reactor in operation. One can guarantee that it will operate after a fashion, but whether it will meet the objectives or not is among the things that one cannot yet foretell because our basic physical, chemical and metallurgical knowledge is still insufficient.

This means that during the design and development of a reactor, there is a very, very violent flux of ideas and changing opinions and changing modes of attack. One will carry through a material that looks particularly good, and theoretically, at least, seems to be just the thing. But then under an actual radiation test, it is found to fall far short of expectations. In the meantime, it is possible that someone experimenting in the physics division has discovered that under a similar type of irradiation for a radically different purpose, a different kind of metal has been used which stood up all right. The new metal, if it can be obtained at all, is immediately tried—and one may find that it works!

There is this constant interplay between the various divisions.

In certain of the research contracts which we have let, we have found that the actual course of the development changed so rapidly that by the time the contract was completed, the actual direction which the development had taken was changed to the point where the results of this particular contract were still very valuable but not critical, as had been anticipated by the participants when the contract was started.

This is disheartening, to say the least, to the people who were putting in their very best efforts on the original contract. One might ask why the character of the work was not changed in the middle. Sometimes this has been done; but sometimes it is somewhat difficult to make such changes after a project is in full swing, particularly when it is known that the results are going to be useful, even though they are not useful in the sense which was originally intended when the contract was put out.

From the foregoing, it is obvious that Argonne is largely concerned with reactor work. We have been convinced from the start that the atomic energy business was either going to be a

business, or not, depending upon whether or not reactors turned out to be really useful in the industrial life of the country. The budget and work program of the laboratory bears this out, even as far as the basic research activities of the laboratory are concerned.

Objectives for Industry

The objective of the laboratory is to make atomic energy a business. The first thing that must be accomplished is to establish a sound foundation on which long-range development can be built. That is one of the major responsibilities at Argonne.

A second responsibility of the laboratory is to bring industry into our program. We are living in a cloister. It is a cloister which is in our estimation justified in many respects. The discussions apropos of secrecy, etc., are less acute within the laboratories where the full story is available than they are outside.

However, there are serious differences of opinion as to where general limits should be drawn, and where the limits should be drawn in particular fields.

This need for security does have very definite effects on the communications problem. It is here that we may be falling down in not bringing to the attention of industry the things that might be of interest to it.

Categories for Cooperation

Cooperation between Argonne and industry falls into two major categories. First, there is what we might call the byproduct business which includes the applications of isotopes. It is in this that the work which we are doing has a direct bearing on the things of interest to industry.

Then there is the second category which includes the direct business of the laboratory itself, the business of developing, building and improving reactors, in which industry can be of direct assistance to us. In general, it is easier to handle the problems in which we can be of assistance to industry than it is to handle the problems in which we ask industry to be of assistance to us.

We have both types of approaches under way at the present time. One which I might mention is the work we are doing with the pharmaceutical people. We have at the laboratory one man from Abbott Laboratories and another from Eli Lilly & Co. who were sent there by their companies to work with the laboratory staff on the problem of the synthesis of radioactive products which cannot be organically synthesized.

The pharmaceutical industry will probably be the first to request a license to operate a reactor for industrial purposes. My guess is that this is obviously something that no single company will want to do. However, on a cooperative basis, it appears that this is one of the things that definitely will come, particularly if the Isotopes Division of the AEC is half as successful with its program as it seems it will be.

If it turns out that in clinical work in the field of medicine, radioactive materials are as valuable as is presently indicated, great gains will be made in medicine. It is the isotopes aspect of the atomic energy field that should probably be placed under control of private industry first.

There are a variety of other and somewhat more minor jobs on which we have been and are now working with industry where the problems are of primary interest to industry but cannot be carried out without the AEC's facilities.

The converse approach is one in which we are also engaged to a considerable extent—getting help from industry on problems of direct interest to us. This becomes a fairly straightforward sort of problem when a reactor is far enough along in design so that the problems become clearly defined. For example, Allis-Chalmers, Babcock & Wilcox, and

several other companies are undertaking direct work in connection with a particular phase of a particular reactor that is under construction.

When it comes to the business of designing high pressure enclosures, we would be foolish to try it in our shop when there are people in industry who are experts at it. But the point is that this type of work has already moved well along into the development part of the program.

One of the difficulties we have is determining which firm is the best equipped to do a particular job. At the present time it is very largely a matter of taking the recommendations of the staff as to who in industry can make the best and the most rapid contribution on jobs of our kind.

Here is where the time factor enters. Our jobs are usually small jobs, as far as industry itself is concerned. In many cases, it may take considerable engineering and design effort to come up with a new-type valve. And yet we may only require six such valves, and the manufacturer will never be called upon to make another one. A request may be received in the meantime for a design of another valve for which there is going to be a demand of several thousand. To prevent delay of the work, it is imperative that we get our valves on the date specified. On occasion we have found it necessary to step into our own design rooms and shops and get the valve built in order to meet our deadline.

In general, our attitude has been that there is no point in installing in our laboratories special equipment and facilities which are available to us in industry. Both Babcock & Wilcox and Detroit Edison are doing work for us in handling high pressure water. It would be foolish for us to attempt to do this work because they have the trained manpower, the equipment, and the know-how to carry these things through to a conclusion far more effectively than we could.

Our problem is how to contact industry. At what point in the development of a project should we make this contact? Then there is also the question of how long a period of time must elapse before industry sees some return on work done by it. These are questions which need answers.

Personnel on Loan

In addition to the contract work, we have at the present time in the laboratory about thirty-five employees on loan from industry. This is a straight, on-the-job training program. By the time these men have lived through one reactor project, they know pretty well what the reactor business is, and they take that knowledge back to their companies.

There is the question, however, of whether we are training the right people. The borrowed man returns to his company as a member of its technical staff, not of its directive staff, and while the company has this know-how in a member of its staff, there is a real question as to whether or not this is really effective as far as the company's planning and thinking for the future are concerned.

What should we do about employees on loan? We have found them extremely useful in our operations, and they have helped us enormously because they have brought with them skills, background and know-how. We could not have done without them. But has it been profitable to the companies to lend them to us?

It is this type of question to which we must find answers before we can plan our own staffing and our own operations in such a way that the cooperation and communication between the Atomic Energy Commission laboratories and industrial laboratories can be made effective.

Fluorescence of Liquids under Gamma Bombardment*

Liquid scintillation counters, with no size limitations, could supplement hard-to-grow crystals in cosmic-ray and other nuclear research. Here is the latest evaluation of the efficiencies of usable solutions, with effects of fluorescent absorption and wavelengths to the ultraviolet considered

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DURING THE LAST FEW months attempts have been made to use liquid solutions for scintillation counters (*1–5*). In a paper now in press (*5*), a more detailed description of the fluorescence phenomena in solutions has been given. In the meanwhile, however, some new results have been obtained.

Table 1 summarizes our measurements on the light efficiency of our best solutions (anthracene is included only for comparison purpose) when excited by gamma radiation and tested with a 1P28 photomultiplier. The last column gives the light emission of the solution relative to an anthracene crystal of approximately the same volume and under the same conditions as the solution. The values shown are integrated intensities rather than peak intensities. Thus this column gives a real measure for the efficiency of the solution.

A new solvent, phenylcyclohexane, has been found which is more effective than any other solvent reported up to now. For comparison, the values for xylene and *p*-dioxane are also included. The increase in light emission in comparison with xylene ranges from about 10% with terphenyl to 50% with alpha and beta naphthylamine and even higher with diphenylbutadiene. The correct values for alpha naphthylamine and diphenylhexatriene are actually larger than those given in the table; the 1P28 photomultiplier is considerably more sensitive in the ultraviolet than in the visible and both alpha naphthylamine and diphenylhexatriene have a fairly strong fluorescence in the visible. Thus the true light efficiency of alpha naphthylamine and diphenylhexatriene are higher than the values given in Table 1 and are nearly the same as that of the terphenyl solution.

Two other substances, iso-durene and durene, have been tested when used as solvents. They give nearly the same value as xylene. The structure of durene consists of four methyl groups on a benzene ring; iso-durene has the same structure but has one methyl group in a different position. Durene is a solid substance but can be used as a solvent for practical purposes by dissolving large amounts in xylene; the amount of durene is so large that it can be considered almost as a solvent.

Durene can also be used as dissolved

* This work was supported by the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey.

TABLE 1

Relative Fluorescence of Solutions Measured with the 1P28 Photomultiplier

Substance	*Solvent*	*Approximate Maximum Concentration gm/liter*	*Relative Intensity*
Anthracene	Phenylcyclohexane	1.5	0.12
"	Xylene	1.4	0.09
m-Diphenylbenzene	Phenylcyclohexane	25	0.24
"	Xylene	35	0.20
p-Diphenylbenzene	Phenylcyclohexane	2.5	0.50
(Terphenyl)	Xylene	5	0.46
"	iso-Durene	4	0.46
"	p-Dioxane	10	0.23
Diphenylbutadiene	Phenylcyclohexane	1.2	0.24
"	Xylene	1.5	0.14
Diphenylhexatriene	Phenylcyclohexane	1	0.27
"	Xylene	1.5	0.20
alpha-Naphthylamine†	Phenylcyclohexane	1	0.33
" "	Xylene	2	0.22
" "	p-Dioxane	10	0.14
beta-Naphthylamine†	Phenylcyclohexane	2	0.28
" "	Xylene	2.5	0.18
Durene*	Phenylcyclohexane	8	(0.11) 0.067
"	Benzene	20	(0.08) 0.058

* Exhibited absorption.
† Exhibited absorption which decreased with further purification.

material. As such it is found to emit a rather large amount of ultraviolet radiation in the region of 3000 A.U. This substance gives the highest light emission yet found in the ultraviolet.

Table 2 gives, for purpose of comparison, the relative light intensity of the solid powdered material (except for diphenylhexatriene because of lack of enough material). Equal amounts of material under the same conditions were tested and compared with anthracene powder. This table clearly shows that the relative intensities are quite different when the substance is used in solution or as a solid. Whereas anthracene has the highest value as powder, it is relatively low in a solution. With alpha naphthylamine just the reverse is true. Durene, both as a powder and in solution, proves to be a strong emitter of ultraviolet light. Its pure ultraviolet radiation as a powder is more than a third of the anthracene readings, and in solution is just about the same as anthracene in the visible.

For scintillation counter work, however, not only these efficiencies are of interest. Absorption of the fluorescent light in the solution itself is of importance. Since in such work relatively large amounts of substance are used, and since the light reflected at the walls of the retaining vessel travels through a much longer path than the length of the container, a very small absorption coefficient of the order of 10^{-1} to 10^{-2} per cm can by itself cause a considerable loss in intensity. It was found (*5*) that even very small amounts of contamination of the order of 0.01 to 0.0001 gm/l , can cause a considerable decrease.

TABLE 2
Relative Fluorescence of Solids

Substance	*Relative Intensity*
Anthracene powder	1.00
m-Diphenylbenzene powder	0.25
p-Diphenylbenzene flakes (Terphenyl)	0.79
Diphenylbutadiene powder	0.75
Durene powder (visible & far ultraviolet)	0.48
Durene powder (far ultraviolet)	0.36
alpha-Naphthylamine powder	0.10
beta-Naphthylamine powder	0.25

These effects of very small amounts of contamination were explained by the assumption that the fluorescent light is absorbed by the contamination and, instead of being re-emitted, is mostly internally quenched.

This explanation has been borne out by undertaking absorption measurements with the fluorescent light of the solutions. For this purpose, the light intensity of the solution was determined as function of the thickness of the solution. If no absorption of the fluorescent light occurs, the intensity should increase linearly with the thickness if the geometrical conditions are suitable and kept constant. This was done for terphenyl in xylene, and a negligible amount of absorption was found. Similar results were obtained for other solutions such as terphenyl and anthracene in different solvents for thicknesses of solutions up to 2 cm. The solutions whose intensity was decreased by a small amount of additional material (e.g. 0.1 gm/l of anthracene in a solution of 1 gm/l of terphenyl in xylene), however, always exhibited a considerable absorption which was in good agreement with the observed decrease in light intensity by the contamination. It is noteworthy that pure anthracene in xylene has no absorption. Neither has terphenyl in xylene, but a terphenyl solution with only 0.1 gm/l anthracene added exhibited considerable absorption. This agrees with the observed weakening of radiation by the added anthracene.

In this manner the absorption test proved to be a good method of checking whether a solution can be improved by purification or not. It was quite generally found that all decreases in intensities by small amounts of contamination (smaller than 0.5 gm/l) stem from an absorption of fluorescent light and an internal quenching of the excitation energy thereafter. The solutions referred to in Table 1 have been tested with this method. Only the solutions marked with an asterisk or a dagger exhibited absorption. The solutions marked with a dagger were additionally purified, and then the absorption went down. Their values in Table 1 are those without noticeable absorption. Therefore, the solutions of Table 1, with the exception of durene, can be used for scintillation-counter work up to thicknesses of several cm. For larger thicknesses, however, some absorption may still occur.

In the case of durene, the situation is different. Our attempts at purification of durene were not able to remove the absorption. A noticeable absorption was always found; this is likely to come directly from the solvent or very likely from contamination in the solvent. The values in brackets for durene indicate the calculated u.v. intensity which would be obtained when all absorption could be removed. Since the fluorescent spectrum is extended over a considerable range of wavelengths, it may sometimes happen that only a part of the fluorescent light is affected.

BIBLIOGRAPHY

1. M. Ageno, M. Chiozzotto, R. Querzoli, *Atti. Accad. Naz. Lincei* **6,** 626 (1949)
2. G. T. Reynolds, NUCLEONICS **6,** No. 5, 68 (1950)
3. G. T. Reynolds, F. B. Harrison, G. Salvini, *Phys. Rev.* **78,** 488 (1950)
4. H. Kallman, *Phys. Rev.* **78,** 621 (1950)
5. H. Kallman, M. Furst, *Phys. Rev.* (In press)

CROSS SECTIONS

Recommendations for Design of Small Cyclotrons*

This article describes in some detail the steps necessary in the design and fabrication of small cyclotrons. It is meant to be merely a guide. Individual cases will no doubt require their own variations from this pattern. Below is a summary of the initial steps necessary:

1. Decide on desired pole gap and diameter.

2. Calculate required ampere-turns taking into account leakage flux.

3. Decide on conductor size as dictated by available power supply or wire; depending on the type of cooling used, this fixes the operating current and, hence, the number of turns.

4. From geometrical considerations, design an approximately rectangular coil.

5. Design the magnet to fit around the gap and coils, leaving enough clearance between coils for accessibility to the tank in the gap. Check on flux leakage criteria mentioned above.

It is well to go through these initial steps for several different designs.

Magnet Design

For most economical performance, it is of course desirable to operate the magnet iron near saturation; most soft irons begin saturating in the vicinity of 16 kilogauss, though some may be operated as high as 21 kilogauss. This figure, however, is not indicative of the field obtainable in the gap. In addition to the flux passing through the gap proper, there is appreciable leakage flux around the periphery of the gap and around the coils themselves. Thus the additional flux causes the pole cores to start saturating well before the field in the gap proper reaches the saturation value. The amount of leakage flux depends on the gap proportions roughly in the following way:

Gap Height / Gap Diameter	*Multiplying Factor*
$\frac{1}{2}$	2
$\frac{1}{4}$	1.5 } Region of small
$\frac{1}{10}$	1.2 } cyclotrons

The required number of ampere-turns is calculated from the indicated formula in the magnet design table, using the *total* gauss passing through the return yoke, that is, the field in the gap multiplied by the above factor. It is also assumed that the length of the pole cores and the distance from pole cores to return yokes is at least twice and preferably three times the gap height. Actually, in small cyclotrons, the required coil space necessitates dimensions such that these conditions are readily met.

As was implied above, saturation should preferably occur in the pole cores only; the return yoke must accordingly be designed so that its total cross-sectional area is a good deal greater than that of the cores, say, at least 25 per cent greater. It is important that the contact surfaces between yoke pieces and between yoke and pole cores be flush to eliminate additional air gaps. The pole core fastenings and coil fastenings should be

* From UCRL-476 by Louis Wouters, University of California Radiation Laboratory; document available for $0.10 from AEC Technical Information Division, Oak Ridge, Tenn.

compatible with the forces as calculated from the design table.

The coils should be wound so that they occupy approximately a rectangular cross section around the poles as shown in Fig. 1. Either too flat or too tall a coil intercepts more leakage flux and thus wastes turns.

The design table also provides formulas for calculation of coil resistance and heating. It is generally advisable to operate close-wound naturally air-cooled coils at a current density not exceeding 750 amp per sq in. of conductor area. For intermittent operation this may be raised to 1,000 amp per sq in. If additional cooling is provided, as described later, this figure may be increased still further. Most coil designs favor large conductor areas and correspondingly high amperages; this reduces total voltage and simplifies both the insulation and the winding problems.

FIG. 1. Coils wound around poles.

As an example of small magnet de-

MAGNET DESIGN DATA

	Annealed Copper	*99.98% Silver*
Modulus of Elasticity—lb/(in.)²	17.5×10^6	11.5×10^6
Specific Weight—lb/(in.)³	0.322	0.380
Resistivity at 20° C—ohm-in.	0.679×10^{-6}	0.641×10^{-6}
Resistivity at 40° C—ohm-in.	0.732×10^{-6}	0.690×10^{-6}
Heat Conductivity at 20° C—watts/in. °C	9.76	10.52
Specific Heat at 20° C—watt-sec/lb °C	174.9	105.9
°C Lin. Coeff. of Thermal Expansion	16.8×10^{-6}	18.8×10^{-6}

Formulas Independent of Material

Ampere-Turns = 2.02 × gauss × inches gap

Lbs force on conductor = 1/1750 × kilogauss × amperes × inches length

Lbs force between pole faces = 1/1.735 (kilogauss)² × (inches² area)

Formulas for Copper and Silver at 40° C Mean Temperature

$$\text{Kilowatt-Tons} = \left.\begin{matrix}(0.118)\text{Cu}\\(0.131)\text{Ag}\end{matrix}\right\} (\text{Mega-ampere turns})^2\,(\text{inches mean turn length})^2$$

$$\frac{\text{Amps}}{\text{Inches}^2} = \left.\begin{matrix}(469)\text{Cu}\\(525)\text{Ag}\end{matrix}\right\} \sqrt{\frac{\text{Kilowatts}}{\text{Tons}}}$$

$$\text{Inches}^2 \text{ conductor area} = \left.\begin{matrix}(2.130)\text{Cu}\\(1.903)\text{Ag}\end{matrix}\right\} \frac{\sqrt{(\text{Kilowatts})(\text{Tons})}}{(\text{Volts})\,(\text{Parallel paths})}$$

$$\text{Inches}^2 \text{ conductor area} = \left.\begin{matrix}(0.731)\text{Cu}\\(0.689)\text{Ag}\end{matrix}\right\} \frac{(\text{Mega-ampere turns})(\text{In. mean turn length})}{(\text{Volts})(\text{Parallel paths})}$$

Formulas for a Rectangular Conductor Losing Heat From Two Edges (40° C Mean Temp.)

$$\text{°C heating at center of conductor} = \left.\begin{matrix}(0.00940)\text{Cu}\\(0.00821)\text{Ag}\end{matrix}\right\} 10^{-6}(\text{In. width of conductor})^2 \left(\frac{\text{Amp}}{\text{In.}^2}\right)^2$$

$$\frac{\text{Watts}}{\text{In.}^2 \text{ edge surface}} = \left.\begin{matrix}(0.366)\text{Cu}\\(0.345)\text{Ag}\end{matrix}\right\} 10^{-6}(\text{In. width of conductor}) \left(\frac{\text{Amp}}{\text{In.}^2}\right)^2$$

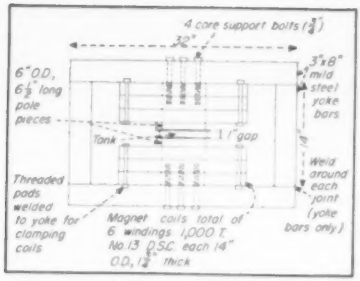

4 core support bolts (¾")
32"
6" O.D., 6½" long pole pieces
3"x8" mild steel yoke bars
Tank
1" gap
Wind around each joint (yoke bars only)
Threaded pads welded to yoke for clamping coils
Magnet coils total of 6 windings 1,000 T. No.13 D.S.C. each 14" O.D., 1½" thick

FIG. 2. Magnet of six-inch cyclotron

sign, the 6-inch cyclotron shown in Fig. 2 has a yoke of area considerably greater than the core area; available standard mild steel bars dictated the indicated dimensions. The yoke frame is welded at the four corners; the cores are each held to the yokes by four long ¾ in. bolts threaded directly into the core iron, which is 6 in. round stock.

The two coils were wound using available #13 D.S.C. wire, each coil consisting of three flat pancake windings of 1,000 turns apiece, for a total of 6,000 turns. Each pancake is 1¾ in. thick, 6 in. I.D. and 14 in. O.D., and is wound toroidally with a layer of 0.005 in. silk or empire cloth tape. These windings saturate the iron (~20 kg) at somewhat less than ten amperes; at this current the temperature becomes excessive in less than an hour.

Three coils are assembled onto the upper pole piece which is already in place on the yoke frame, with the lower pole piece removed. They can be held in place by insulated brass clamping bars bolted to the upper yoke piece. The other three coils are placed on the lower pole piece which is then slid into position and bolted down; similar coil clamping can be used.

Cooling plates could be inserted between each coil layer as well as on top and bottom of each coil assembly. These consist of flat donuts of 1/16 in. copper sheet, with a 6 in. I.D. cut-out and 15 in. O.D., having a ¼ in. copper pipe soldered to the outer edges. During operation cold water is run through this set of pipes; together with a large fan for general circulation, such coils should operate steadily at 1,300 amp per sq in.

Magnet Supply

For magnets of this size, a variety of supplies are available. Among the more convenient are the motor-generator set and the selenium-oxide rectifier.

The motor-generator set is most easily available since almost any d-c arc welding outfit can be modified for this purpose. Current control should always be inserted in the field exciting winding. The magnet coil circuit must never be broken at high currents, of course, unless adequate surge protection is provided. This can consist of a Thyrite resistor unit or an electrolytic tank of suitable size.

The selenium-oxide unit has no moving parts and will last almost indefinitely, but is more expensive. Current can be controlled by means of a Variac installed in the a-c power line.

Tank Design

In this size range, it is possible to use either glass or metal systems; the availability of reliable high speed pumps make the latter more attractive. The six-inch cyclotron tank as shown in Fig. 3 will be used as an example of a suitable arrangement of components.

The top and bottom of the vacuum chamber should be thin, circular steel plates (not much larger than the pole diameter), in order to decrease the magnetic gap as much as possible. To prevent field bypassing, the tank wall must be nonmagnetic, preferably brass; the bottom plate is soldered to this wall. This is convenient from the standpoint of assembly of the other components. The top plate is sealed by means of a quite orthodox rubber seal.

The various operating elements are held in position and sealed through the

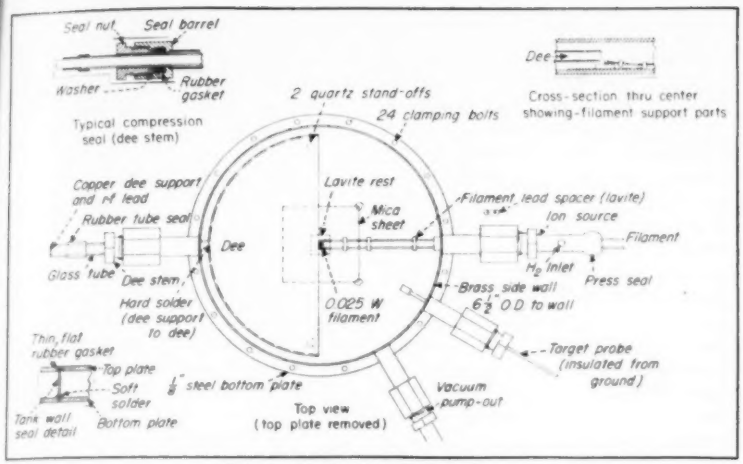


FIG. 3. Tank of six-inch cyclotron

tank wall by means of compression seals, a typical one being illustrated in the sketch in Fig. 3. The seal support pipes are soldered directly into holes in the tank wall.

The vacuum pump connection simply has a ½ in. glass pipe passing through the seal, opening into the tank. Evacuation is done progressively by a small mechanical pump, a mercury or oil diffusion pump, and a liquid air trap. Vacuum system techniques similar to those used in any physics laboratory are adequate here. An ionization gage is the most flexible and reliable means of measuring high vacuum, and is sufficiently accurate. For low vacuum either a McLeod or thermocouple gage is used. For operation, a preliminary vacuum of about 10^{-5} mm Hg should be attained; during "bakeout" pressure should not exceed $\sim 10^{-3}$ mm. Operation as a cyclotron can be attempted with a pressure of 10^{-4} mm or less with all r-f and source power applied.

The ion source connection consists of a ½ in. pyrex tube passing through another compression seal for a distance of ¼ in. into the tank. This provides insulation for two heavy (0.060 in. to 0.100 in.) wolfram wires which enter through a press seal at the outer end of the glass tube. These wires are spaced by small ceramic (lavite) spacers; immediately beyond the glass tube the wires bend down and follow close to the tank bottom, to avoid interfering with the beam orbits. At the center of the tank, a filament is spot welded to these leads. In the past, an automobile headlight filament has been used, but the breakage has been high. A somewhat heavier wire seems appropriate, perhaps 0.025 in. wolfram. This filament rests on a small flat ceramic square which fits into the mica sheet as shown in the sketch; the latter is fastened to the tank bottom by means of a drop of sealing wax at the two corners *away* from the dee and filament. The hydrogen inlet is a small tubulation in the side of the glass tube; the hydrogen flow can be controlled by means of a needle valve having a long tapering needle fitting into a long tapered seat. Alternative methods employ the leakage of gas past a loose fitting thread, the flow being controlled by the number of engaged

threads of screw, or, as in the case of the 6-inch cyclotron, the use of a palladium metal valve, in which flow is controlled by the diffusion rate of hydrogen through thin electrically heated palladium.

A 0.025 in. wolfram filament requires about 25 amp d-c at a few volts for operation; this can be readily obtained, for instance, from a heavy duty battery charger floating across a storage battery. The storage battery acts as a very large filter capacitor, being necessary to prevent violent vibration of the filament system which would result from unfiltered ripple. Current control is obtained by means of a series resistor. There must also be supplied the d-c arc voltage and current, which appears as a negative bias between filament and tank ground. At normal operating pressures of 10^{-4} mm Hg, $\frac{1}{2}$ to 2 amp at 100 to 500 volts will be required.

The target connection is simply a $\frac{1}{8}$ in. brass rod passing through a greased compression seal. The inner end is threaded, so that small metal targets may be mounted there.

The dee connection must be carefully insulated; this is accomplished by slipping a $\frac{1}{4}$ in. Pyrex tube completely over the $\frac{3}{16}$ in. copper dee support rod from the dee edge to at least 2 in. beyond the seal. The compression seal then seals to this glass tube, and a separate seal is made at the outer end of the glass tube by slipping a short section of greased $\frac{3}{16}$ in. rubber tubing over that end as shown in the sketch. The dee is 6 in. across and $\frac{1}{4}$ inch high and is made of $\frac{1}{32}$ in. copper sheet except for the edge strip which is $\frac{1}{16}$ in. copper. In this unit, it is further supported by a $\frac{1}{4}$ in. quartz stand-off under each corner. The r-f dee voltage may be as high as 3 kv, which voltage is supplied by an oscillator such as that described in the next section.

The general tank arrangement need not follow the indicated layout; however, mechanical convenience requires more or less opposite placement of dee and ion source stems. It is also convenient to place the other seals to one side of the dee and source center line, so as to facilitate inserting the final tank assembly into the magnet gap.

An unusual feature is the "single-dee" construction; this has many advantages in simplifying tank and oscillator construction. The "other dee" is, of course, the tank proper. Better ion focussing can be obtained by installing a "dummy" grounded dee edge symmetric to the insulated dee, but this refinement should be attempted only after the apparatus is operative.

The Oscillator

The accompanying circuit as shown in Fig. 4 has been employed successfully in this service; it is a grounded grid Hartley. We have found that the greatest problem with any oscillator circuit lies in confining the r-f current to the desired paths. Neither a circuit nor a layout can show this realistically; however, it is easier to confine the r-f currents to the diagrammed circuit in the case of the grounded-grid Hartley than in most other circuits. The dee-to-ground capacity appears as the major portion of the capacitance in the *LC* tank circuit, which must be calculated taking this into account; C_1 acts as a trimmer to adjust the frequency more precisely. A step-up in r-f

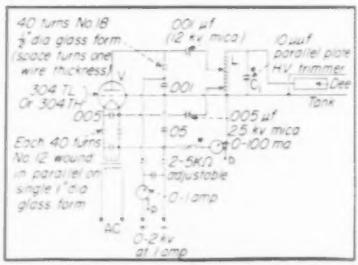


FIG. 4. Oscillator circuit

voltage is achieved by tapping down the plate connection. Note that neither side of the power supply can be grounded, the negative side rising up to the grid bias potential as the oscillator starts up.

In making the r-f connections, it is important to provide short, broad paths for current flow, especially in the ground circuits. A good design is to mount the tube through a large hole in a copper ground sheet such that this sheet is at the level of the grid terminal. The connection to that tube terminal can be simply a sturdy clip mounted directly on the edge of this ground sheet; the ground sheet can then extend up to the tank well. The coil, chokes and condensers may be grouped roughly as shown in the schematic layout in Fig. 5. While the tube should be placed as close to the tank as possible, it must yet be kept away from the magnetic field.

The radiofrequency voltage can be measured directly, if desired, by means of a V. T. diode voltmeter (employing, for instance, a high-voltage, high-vacuum diode made for the purpose) connected to the lead to the dee.

General Precautions

The voltages employed on the various cyclotron components are deadly; proper precautions must be taken, even during preliminary testing, to insure safety to personnel. Interlock switches on the power supply covers and grounding hooks in the vicinity of the cyclotron must be provided. A well-grounded copper screen box around the oscillator will help keep the r-f from interfering with the other circuits.

The sample general circuit layout gives an idea of the space and electrical requirements. All circuits connected to tank elements should have adequate choking and bypassing to prevent r-f from reaching the meters and supply lines. The operating controls and meters, especially those connected to magnet, source and r-f power, should be

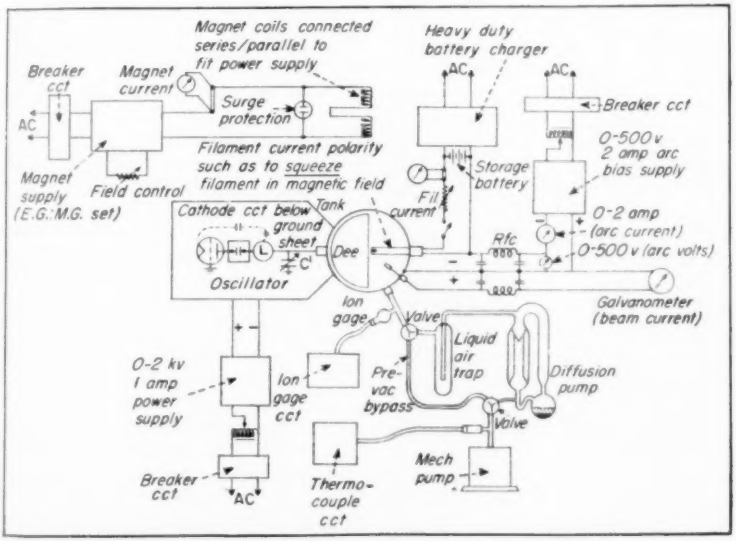


FIG. 5. Schematic layout of cyclotron circuit components

readily adjustable and easily shut off, as by push-button control circuits.

Prior to final tank assembly, preliminary washing of the parts in CCl_4 is recommended to remove organic matter. It is wise to avoid undue exposure to carbon tetrachloride vapor.

Operation

Assuming that all leaks have been successfully patched (glyptal may be used) and that a satisfactory base vacuum (10^{-5} mm) has been obtained, the next step is "baking-out." Radiofrequency power should be initially applied in short bursts, under reduced power (r-f power control is conveniently obtained by means of a Variac in the plate power supply). Glow discharges accompanied by large increases in tank pressure will be observed; r-f power should never be left on for prolonged periods under these circumstances, else the risk is run of cracking the glass dee insulators. The power and length of application should be gradually increased until the vacuum remains less than 10^{-4} mm with r-f on steadily, at perhaps 2 kv. If this cannot be easily attained, it may mean the presence of organic matter in the tank, such as grease, cutting oil, or rubber. Sometimes turning on the magnetic field will aid in baking-out.

The filament should now be turned on gradually, with the magnet on and r-f off, and with perhaps 150 volts of arc bias applied. When thermionic emission starts, there will be some residual gas arcs, following which the arc voltage should be shut off until pressure returns to normal. The filament should be adjusted so that under high vacuum conditions, a moderate emission current (10–20 ma) is observed with 200–300 volts arc bias. The r-f power can now be turned on once again at reduced level, and the baking-out process repeated.

When a good vacuum (10^{-4} mm) exists with magnetic field and all power turned on, hydrogen may be admitted to the tank, "opening" the valve until the tank pressure rises by another 10^{-4} mm, meanwhile watching the arc current. (Depending on the type of valving employed, it may be necessary to first flush out any trapped air in the H_2 system.) The arc can be "struck" by carefully raising filament current or arc voltage—an arc of $\frac{1}{2}$ to 1 amp at 100 to 200 volts is usually satisfactory.

One can now start looking for a beam—the radiofrequency and magnetic field are adjusted near resonance, and either one rocked back and forth until a current peak is indicated on the target probe. The probe may be pushed in closer to the center to facilitate locating this resonance. Then it may be withdrawn, meanwhile optimizing arc, filament and r-f power by the beam current indication. The target probe must show a high resistance to ground; of course, a sensitive galvanometer (protected by r-f chokes and bypasses) may be used initially for detecting the beam current, though it should be possible to obtain a few microamperes deflection on a standard 0–20 microampere meter. The six-inch cyclotron has indicated a 7 microampere beam, at a frequency corresponding to about 800-kv protons. It is often possible to obtain current readings due to ions reaching the probe by other than cyclotron paths. Thus, the authenticity of the beam should be checked by the sharpness of resonance as a function of r-f tuning and magnet current, as well as by its sensitivity to hydrogen gas pressure. Background currents are generally quite insensitive, being "broad" in adjustment compared to the true beam.

Of course, the final check lies in the detection of nuclear events resulting from the bombardment of the target by high energy protons. Suitable reactions for this purpose may be found in

the light isotopes; a convenient target substance would be LiF which, when bombarded with protons, will emit gammas from Li with 0.2 Mev threshold and from F with 0.3 Mev threshold. The target may be prepared by simply fusing a small amount of LiF onto a small stainless steel block on a probe.

The size of the machine depends on its purpose, of course. For educational applications a six to nine-inch pole piece is an economical range; for inducing light element reactions, it is probably worthwhile thinking of a somewhat larger machine, say, 12 to 15 inches, so that at least enough energy is available for some neutron-yielding reactions. In this size, the economics of magnet construction require "tighter" design than has been set forth here.

Radio-Controlled Liquid Level Device Developed

A radio-controlled liquid level device was recently developed at Oak Ridge.* The instrument was designed to indicate remotely the levels of highly radioactive and highly corrosive liquids.

The essential elements of the system are a 100-Mc oscillator; two quarter-wave coaxial lines of stainless steel into which the oscillator output is coupled, and which are immersed in the liquid to be measured; an amplifier; a motor; and an indicating meter.

The function of the quarter-wave lines is similar to that of a ratio-detector in an f-m receiver. Because of the conductivity of the liquid, the electrical length of these lines, relative to the oscillator output frequency, is determined by the amount of line shorted out by the liquid (in other words, by the height or level of the liquid).

* Developed by Kenneth Kline of the Circuit Development Section of the Instrument Department of Oak Ridge National Laboratory. The work was supervised by Frank Manning, supervising engineer of the section.

Experimental High-Megohm Resistors Developed

In order to maintain constant and accurate measurement with analytical mass spectrometers, it has been necessary to overcome a number of electronic problems. One, which occurred in the electrometer circuit used with the spectrometers, involved high-value resistors. Equipment and techniques for several experimental types of resistors (see

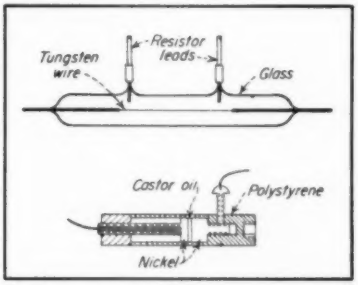


illustration) have been developed† in ranges of about 4×10^{10} ohms. The most promising types seem to be the oil-filled and the metallic films sputtered on glass. Castor oil was used as the resistance element in a suitably constructed resistor having little capacitance, very fast time constants, and little noise. Resistors of this type are difficult to construct, and should the oil become at all contaminated, a lower resistance value results.

The resistor made of a tungsten film sputtered on the inner surface of a glass cylinder also has a rapid time constant and is easily fabricated. Care must be taken during the oxidizing process since the tungsten oxidizes very readily, resulting in a considerable decrease in resistance value. Lack of special equipment has delayed the perfection of a practical resistor of either type.

† From AECU-618, by K. E. Burmaster, Carbide and Carbon Chemicals Corp., available at $0.10 from the Technical Information Division, ORE, U. S. AEC, Oak Ridge, Tenn.

NUCLEONIC EVENTS

PIKE NOMINATION HELD UP; DEAN, MURRAY, SMYTH STAY

The Senate last month confirmed new terms for only three out of the four members of the United States Atomic Energy Commission whose terms expired on June 30 and whose reappointment was sought by President Truman. In accordance with the original provisions of the McMahon Act, which calls for staggered terms for the commissioners, Gordon Dean was reappointed for a three-year term, Thomas E. Murray for a two-year term, and Henry DeWolf Smyth for a one-year term. Up to last week, the reappointment of Sumner T. Pike, the only remaining member of the original five-man Commission and acting chairman since David Lilienthal's resignation on February 15, was delayed. The Senate members of the Joint Congressional Committee on Atomic Energy voted 5 to 4 to deny Mr. Pike a new term, but on July 10, the full Senate confirmed his nomination for a four-year term.

Dr. Smyth, who is the scientist member of the Commission, requested the one-year term to perpetuate the policy attributed to his predecessor, Dr. Robert F. Bacher, whose views he shares in regard to the length of time the scientist member should serve. A one-year term, these men believe, would enable more scientists to serve on the Commission and thus provide them with a better appreciation of the AEC's administrative problems.

N. R. BEERS DIES; RESIGNED FROM "NUCLEONICS" JUNE 1

The publishers and staff of NUCLEONICS regret to announce the death on June 27 of Norman Ritner Beers. Mr. Beers had been Editor of NUCLEONICS from April 15, 1949, until June 1, 1950, when continued ill health forced him to resign the position.

He had come to NUCLEONICS from Brookhaven National Laboratory where he was leader of the meteorology group. He was a Rhodes scholar, co-author of the "Handbook of Meteorology" and during 1946–47 was associate professor of aerological engineering at the Postgraduate School at Annapolis. Prior to the war he was with the McGraw-Hill Book Company and spent the years 1941–46 in the U. S. Navy.

On June 1, Keith Henney reassumed the title of Editor, which he had held during the period 1947–49. He will be responsible for top policy. At the same time, Jerome D. Luntz, who has been on the editorial staff of NUCLEONICS since its inception, was appointed Executive Editor. Mr. Luntz will be responsible for the editorial operations of the journal.

AEC ORDERS NEW PILOT PLANT FOR CHEMICAL PROCESSING

The Atomic Energy Commission recently authorized construction of a $500,000 pilot plant for chemical processing at the Wabash River Ordnance Works in Vermillion County, Indiana. No radioactivity will be involved in the operations.

A small part of the space in the ordnance plant now is occupied by the Commission, but the existing facilities have been in standby since 1945 and are outmoded and inefficient.

If the pilot plant process proves suc-

cessful, the Commission will modify the rest of the space or install new facilities. Renovation of these facilities and installation of new equipment are expected to cost about $5,000,000.

Construction of these facilities, if undertaken, will begin this summer and will require 18 to 20 months to complete.

The Girdler Corporation of Louisville, Kentucky, is completing studies on the feasibility of the process.

ARGENTINA ESTABLISHES AN ATOMIC ENERGY COMMISSION

Argentina's president Juan D. Peron, in a decree published last month, created a national atomic energy commission. The decree places the commission in charge of nuclear research in Argentina, with powers to supervise all public and private research. The commission also will propose means of defense against atomic warfare and of harnessing atomic energy for peaceful use.

All persons engaged in atomic research in Argentina were ordered to report to the commission immediately.

Argentina is the first South American country to set up such a body.

BROOKHAVEN IS HOST TO BIOLOGY CONFERENCE

About 80 persons attended a biology conference sponsored by the Associated Universities, Inc., and held at the Brookhaven National Laboratory in Upton, New York, on June 7 and 8.

Papers scheduled for discussion included: *Introductory comments on CO_2 fixation*, by Harland G. Wood, Western Reserve University; *The mechanism of the fixation of CO_2 in dicarboxylic acids*, by M. F. Utter, Western Reserve University; *Glucose, pyruvate and glycogen metabolism in rat liver*, by A. Baird Hastings, Harvard University; *Biosynthesis of dicarboxylic and tricarboxylic acids by CO_2 fixation*, by Severo Ochoa, New York University; *Organic acid synthesis by C_2 condensation and reversible CO_2 exchange reactions*, by S. F. Carson, Oak Ridge National Laboratory; *β-Carboxylases and related enzymes in the tissues of higher plants*, by Birgit Vennesland, University of Chicago; *Organic acids in photosynthesis by higher plants*, by Robert E. Stutz, Argonne National Laboratory; *Assimilation of CO_2 by soybean leaves in relatively early stages of photosynthesis*, by S. Aronoff, Iowa State College; *CO_2 fixations in*

ABOUT THE COVER

PROTON RECOIL tracks, caused by fast neutron bombardment of photographic plates, are detected with the scanner shown in the cover picture. Designed and constructed at Battelle Memorial Institute in Columbus, Ohio, it is used for analyzing intensity and energy distribution of neutron sources. A nuclear plate, mounted on the disk in the center of the picture, passes under an oil-immersion microscope objective once each second as the disk rotates. The microscope mount turns slowly, moving the lens more or less radially across the disk. Any proton-track image in the emulsion is detected by photomultiplier in box on top of microscope tube. The resultant signal is amplified and used to actuate recorder which shows position of track. Mirror in center of disk is used with telescope and scale to relocate tracks. Photo by Ernst from Battelle Memorial Institute.

photosynthesis, by A. A. Benson, University of California; and *Distribution of labeled carbon in the sugars of sunflower leaves after exposure to $C^{14}O_2$ in the light and dark*, by M. Gibbs, Brookhaven National Laboratory.

SPEAKERS ANNOUNCED FOR OAK RIDGE SYMPOSIUM

The principal speakers and the topics they will discuss at the second annual Oak Ridge Summer Symposium, devoted this year to quantum and inorganic chemistry, are as follows:

Peter Debye (Cornell University), *New Developments in Polymers and Colloidal Solutions;* Henry Eyring (University of Utah), *Reaction Kinetics;* Herbert S. Harned (Yale University), *Present Status of our Quantitative Knowledge of Electrolytic Solutions;* Linus C. Pauling (California Institute of Technology), *Electronic Structure of Molecules and Crystals;* George Scatchard (Massachusetts Institute of Technology), *Physical Chemistry of Solutions.*

As previously announced (NU, Apr. '50, p. 80), the symposium will take place August 21-31. Free of security restrictions, it will be held in an air-conditioned building in downtown Oak Ridge, Tennessee.

The committee in charge of the program include Drs. G. E. Boyd, M. A. Bredig, K. A. Kraus, H. A. Levy, and S. C. Lind.

12 NEW RESEARCH CONTRACTS AWARDED BY AEC

The U. S. Atomic Energy Commission awarded the following 12 new contracts for physical and chemical research totaling $1,345,660 during the first three months of 1950:

California Institute of Technology
Supervisor: Dr. Robert F. Bacher
For: ($1,250,000) Design, construction and operation for 3 years of a 1-Bev electron synchrotron.

George Washington University
Supervisor: Dr. C. R. Naeser
For: Studies of the fluorides of the rare earths.

New York University
Supervisor: Dr. C. V. King
For: Measurement of metal dissolution rates in aqueous solutions of acids and oxidizing agents.

Pennsylvania State College
Supervisor: Dr. P. J. Elving
For: Research on polarography of organic compounds.

University of Florida
Supervisor: Dr. D. O. Swanson
For: Completion of 1-Mev electrostatic generator now under construction.

University of Illinois
Supervisor: Dr. P. E. Yankwich
For: Research on hot-atom chemistry and isotopic exchange reactions primarily between uncomplexed ions.

University of Louisville
Supervisor: Dr. R. H. Wiley
For: Research on synthesis and properties of ion exchange resins.

University of New Hampshire
Supervisor: Dr. H. H. Haendler
For: Studies of certain uncommon inorganic fluorides.

University of North Carolina
Supervisor: Dr. S. Y. Tyree, Jr.
For: Study of molecular compound formation between zirconium tetrachloride and certain organic esters.

University of Puerto Rico
Supervisor: Dr. A. Cobas
For: Low latitude cosmic ray studies.

Western Reserve University
Supervisor: Dr. E. L. Pace
For: Studies of thermodynamic properties of gases adsorbed on solids.

Yale University
Supervisors: Drs. L. Meites, J. M. Sturtevant
For: Study of polarographic diffusion with objective of increasing the accuracy of the polarographic method of chemical analysis.

Dr. Kenneth S. Pitzer, director of the AEC division of research, who made the announcement of these contracts, said that in the same period the AEC also renewed an existing contract with the Case Institute of Technology, Cleveland, O. This contract is for the study of gamma-ray spectra produced with a 30-Mev betatron; the work is supervised by R. S. Shankland and E. F. Shrader.

IN BRIEF

➤*Twenty-three industrial corporations presently are contributing $700,000 to the support of the annual research budget of the University of Chicago's institutes for*

nuclear studies, radiobiology and biophysics, and metals.

➤Gibbs & Hill, Inc., New York and Los Angeles, have been selected to design the major permanent power facilities for the reactor testing station near Arco, Idaho. Construction cost is estimated to be in excess of $1,000,000,

➤*The Canadian House of Commons has been told that yield from sales to industry of radioisotopes from the Chalk River atomic energy plant will be $250,000 to $300,000 in 1950–51.*

➤Congress has been asked for $600,000 for AEC biological research at the Monsanto Chemical Company's Dayton works during the fiscal year.

➤*$18,900,000 is expected to be required during the fiscal year for construction at the AEC's Arco plant.*

➤The Knolls Atomic Power Laboratory, recently completed $26,000,000 facility which the General Electric Company operates near Schenectady, N.Y., for the AEC, has been established as a self-contained integrated operation. It had formerly operated as a division of the G-E Research Laboratory.

➤*Development of 4-Mev linear acceleration equipment for cancer treatment and nuclear physics research will be announced by North American Philips Company, Inc., at the International Radiological Congress taking place in London July 24–26. The first unit is now in operation in England. Developed by radar scientists, it produces ultra-high penetrating X-rays and has a rating of approximately 250 roentgens per minute at 40 inches.*

➤An electromagnetic separation plant has just been completed at the British Atomic Energy Research Establishment at Harwell, and construction of a new atomic energy installation has been started at Aldermaston, near Reading.

NUCLEAR NEWSMAKERS

John R. Dunning has been appointed Dean of Engineering of Columbia University to replace **James K. Finch** who retired from the post on June 30. Dr. Dunning will continue to function as director of the university's scientific research, which includes that currently being carried on with Columbia's new synchrocyclotron.

Percy W. Bridgman, Harvard professor and Nobel Prize-winning physicist, recently received the honorary degree of Doctor of Science from Princeton University.

William H. Milton, Jr., has been appointed general manager of the Knolls Atomic Power Laboratory. He resigned as General Electric Company's commercial vice president with headquarters in Washington, D. C., to accept the new post.

D. W. Pearce has been named assistant to **A. B. Greninger,** manager of the technical division of the Hanford Works. He will be responsible for educational matters, procurement of scientific personnel, and liaison with technical activities of other atomic energy sites. **F. W. Albaugh** will replace Dr. Pearce as head of Hanford's analytical section.

Winfield W. Salisbury, director of research for the Collins Radio Company, nuclear engineer, and editorial consultant to NUCLEONICS, last month received the honorary degree of Doctor of Science from Cornell College in Iowa.

Enrico Fermi has been named recipient of the 1950 Barnard gold medal, awarded every five years by Columbia University for "meritorious service to science." Dr. Fermi, a former Columbia professor now conducting nuclear physics research at the University of Chicago, received the medal on the recommendation of the National Academy of Sciences for his work in quantum

mechanics and theoretical and experimental research on the atomic nucleus.

George C. Butler has been appointed acting counsel of General Electric's nucleonics department at Hanford Works. He replaces **Lewis F. Huck** who last month assumed duties as community manager of Richland, Washington.

Sam Norris has been elected president of the Amperex Electronic Corporation. He moves to this position from that of executive vice president.

David F. Shaw on June 1 became manager of the Hanford Operations of the AEC's atomic energy program. Formerly assistant manager and deputy manager of the Hanford office, he succeeds **Fred C. Schlemmer** who resigned to re-enter private industry.

J. C. Robinson has been appointed to the post of chief process engineer in AEC's Reactor Development Division in Washington, D. C. He was formerly with the AEC's office of production and engineering at Oak Ridge.

Vannevar Bush, president of the Carnegie Institute at Washington, and **William Shainline Middleton,** president of the American College of Physicians, received the honorary degree of Doctor of Science last month from Cambridge University.

NECROLOGY

Helmut L. Bradt (May 24, 1950)· Physicist and cosmic-ray specialist, Dr. Bradt, together with Bernard Peters and Morton Kaplan, was credited with obtaining photographic evidence of the neutral meson last January. He was on the faculty of The University of Rochester.

R. C. Mason (May 12, 1950). Physicist and author of twenty scientific papers dealing with the electrical conduction of gases, Dr. Mason was, up to the time of his death, manager of the Physics Department of the Westinghouse Re-

(Continued on page 94)

BOOKS

Nuclear Physics—A Course Given by Enrico Fermi at the University of Chicago. (Revised edition.) Notes compiled by Jay Orear, A. H. Rosenfeld, and R. A. Schluter, The University of Chicago Press, Chicago, Ill., 1950, ix + 246 pages and 1 fold-out chart, $3. *Reviewed by Ralph E. Lapp, Nuclear Science Service, Washington.*

Only a relatively few students are privileged to attend Professor Fermi's brilliant lectures at the University of Chicago; it is therefore a distinct contribution to the followers of nuclear science that his lecture material has been systematically organized in a publication and made available to a much wider audience.

An introductory chapter on the properties of nuclei is followed by a thorough discussion of the interaction of radiation with matter. The theory of alpha, beta, and gamma emission from nuclei is treated on a rigorous theoretical basis. Nuclear forces and meson theory form the subject matter of two additional chapters, and the book is rounded out with a discussion of neutron physics and cosmic radiation.

The text is interspersed with illustrative examples and problems that can prove of great value both to the student and to the professor. In such an advanced treatment of the subject, appropriate examples are difficult to set forth, and here Professor Fermi and the compilers deserve special commendation for including fairly complete solutions to the problems.

Those who prepared the book should be encouraged to have the text set in readable type, the equations made more legible, and the illustrations transformed from their present blackboard-

sketch appearance into finished line drawings. One hopes that the University of Chicago Press will be persuaded to publish Fermi's "Nuclear Physics" in a form consonant with its importance to science.

Introduction to Nuclear Physics (Einführung in die Kernphysik), 4th edition, by Wolfgang Riezler, Herman Hübener Verlag, Stader Strasse 84, Buxtehude, Germany, 1950, 309 pages, 8 plates, 1 pull-out chart, price DM 16.00 (linen binding, DM 17.50). *Reviewed by Martin Deutsch, Department of Physics, Massachusetts Institute of Technology.*

This volume is the fourth edition of a work which first appeared in 1937 and has become the most popular introductory text in nuclear physics in Germany. It is addressed to beginning students of modern physics and to workers in other fields of the natural sciences. In accord with this intended audience, the book is written almost without mathematical symbols and formulas. Despite this restraint in the use of the most powerful expository tool of the physicist, the presentation is in general remarkably rigorous, more so than many texts making far greater demands on the formal preparation of the reader.

The main body of the text is divided into seven chapters entitled: *Nuclear Physics as a Science; Properties of the Nucleus; Radioactivity; Nuclear Reactions; Nuclear Structure; Methods of Nuclear Investigations;* and *Applications of Nuclear Physics.* This is followed by a series of tables of properties of stable and radioactive nuclei including a chart of nuclides, a brief bibliography and a glossary of general physics terms.

The first five chapters forming almost exactly half of the volume are its best part, presenting a great deal of correct information in an easy, yet penetrating, manner. Occasional errors such as the misleading discussion of complex alpha-ray spectra (p. 53) and omissions such as the lack of any discussion of elementary particle scattering may be forgiven in a book of this type. A few specific references to important original papers might have helped the reader to correct some of the gaps.

The bibliography lists 10 books on nuclear physics and 28 selected review articles (all in German), but no original papers.

Against these faults one may balance the fluent style and uninterrupted presentation. The 43 figures in the first half of the book and most of the eight plates at the end are well selected.

The long chapter on methods of nuclear investigations is weak and almost useless for an American reader. Undue emphasis and detail are devoted to obsolescent methods. Almost two pages are devoted to the experimental precautions required for proper visual observation of alpha-ray scintillations. Three different circuit diagrams for linear amplifiers are given in full detail, including alternate choices for the tubes used but, in the discussion of gain-stability, feedback is not even considered. Electron collection is not mentioned in twelve pages devoted to ionization chambers.

There are certain peculiarities which remind one of the fact that the first three editions of this work were written between 1936 and 1943 in the poisonous mental atmosphere of the Hitler decade and that the present volume is not without its signs of inadequate denazification. Thus, quantum mechanics is credited (p. 14) entirely to Heisenberg without mention of Planck, deBroglie, Schroedinger or Dirac. $E = mc^2$ is ascribed to Hasenoehrl and Einstein (p. 28). After implying that Kerst pirated the design of the betatron from Seebeck (p. 170), the author mentions two relatively small German machines

constructed during the war years and names their designers and the companies that built them.* The reader is left with the impression that nowhere else in the world were betatrons constructed. It is hardly an accident that the only direct quotation documented with a definite reference in the whole volume is a remark by Wigner to the effect that the entire work of developing a workable nuclear chain reactor was duplicated independently by German nuclear physicists (p. 173). In line with this preferential treatment of some workers, the section on tracer techniques (pp. 233–44) quotes Riezler and collaborators three times by name in the discussion of radiocopper while the work on radioiodine, otherwise discussed in equal detail, was apparently done by anonymous gremlins.

It may be said in fairness, though, that the author's *explicit* statements on such matters as the position of pure and applied science (p. 231), bureaucratic interference with research (p. 12), and the moral position of the physicist in regard to military applications (p. 253) are parallel with the views of most American scientists. This reviewer does not know how many of these views were expressed in earlier editions.

Science Is a Sacred Cow, by Anthony Standen, E. P. Dutton and Company, Inc., New York, 1950, 221 pages, $2.75. *Reviewed* by *Lillian Wald Kay, Dept. of Psychology, New York University.*

"It is not the intention of this book to deny or belittle the useful things that science has done, but neither is it necessary to say much here about the achievements of science, because there are so many science publicists already busy doing that" (page 137). Except for the claims to "impressive learning" on the dust cover, this is the nearest thing to a statement of purpose one can find in the book. Such a statement is missed because it is not otherwise possible to determine what the author is aiming at.

No one can argue with his statement that, at this time, scientists have great prestige because of the public's impression of the actual and potential achievements of science. This is nothing new. The medical profession—which Standen omits from his survey of sciences and humanities—has long been held in such esteem. Problems do arise from his interpretation of what follows from this fact.

There are some exaggerated versions of science education as we now practice it. Is Mr. Standen annoyed because of the way in which science is taught or because of its prominence in curricula or because it does not lead to desirable qualities of accuracy and observation? Each of these is a legitimate subject for investigation, but no issues are clarified by imaginary examples or carefully selected quotations which fit the author's prejudices.

Similarly, it is his privilege to examine the methods and interests of the various sciences and to draw his conclusions as to the place of each in a hierarchy. He is right in saying that social science and psychology err in trying to ape the physical sciences. However, if his point is that psychology is the proper study of man, that the social sciences deal with the most important questions, it is not helpful to attack the methods of these fields on the basis of physical science criteria.

The most controversial part of this book is the last chapter, "Watch Those Scientists." Again, many people would agree that we need to be at least as aware of social issues as of physical science at this time. The tone of much of this chapter, however, may

* Editor's Note: Work done with one of these machines, a 6-Mev betatron, is described in a paper by K. Gund and W. Paul on page 36 of this issue of Nucleonics.

well reinforce ignorant suspicions. The scientist who reads this book will find himself alternating between amusement (particularly when somebody else's field is being raked over the coals) and resentment (at the misrepresentations of everybody's work). Mr. Standen's unscientific version of the aims of scientists (physical and social) can only confuse the issue for laymen who, impressed by any scientist, may take him seriously.

BOOKS RECEIVED

Medical Physics (Vol. 2), edited by Otto Glasser, Year Book Publishers, Inc., Chicago, Ill., 1950, xxvi + 1227 pages, 978 illustrations, $25. As a supplement to Vol. 1 of this work, which was published in 1944, Vol. 2 reflects the stimulus which the development of atomic energy has made in all areas of medical research. Radiation therapy, neutron diffraction, G-M counters, radioisotopes, high-energy accelerators, and radicautography are among the many chapter titles noted of particular interest to NUCLEONICS readers.

Supervoltage Roentgentherapy, by Franz Buschke, Simeon T. Cantril, and Herbert M. Parker, Charles C Thomas, Publisher, Springfield, Ill., 1950, xiii + 297 pages, $10.50.

OTHER LITERATURE

Handbook on Aerosols. This is a 147-page pamphlet published by the U. S. Atomic Energy Commission in connection with its program for control of radioactive wastes at atomic energy facilities. It consists of 11 chapters by various authors, originally prepared as part of the Summary Technical Report of Division 10, National Defense Research Committee. It is directed to engineers and others charged with preventing atmospheric contamination by radioactivity who need basic knowledge of the behavior of dusts, fumes and mists. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., 60 cents.*

A Glossary of Uranium- and Thorium-Bearing Minerals, by Judith Weiss Frondel and Michael Fleischer (*Geological Survey Circular 74*). Released recently by the U. S. Dept. of the Interior, this glossary contains a list of minerals and their chemical formulas, together with information on series relationships collected from laboratory work and scientific literature. *Available without charge from the Director, U. S. Geological Survey, Washington 25, D. C.*

(Proceedings of the) Second Annual Joint AIEE-IRE Conference on Electronics in Nucleonics and Medicine. Published March, 1950, this booklet contains the papers presented at the conference held in New York, Oct. 31, Nov. 1–2, 1949. *Available from American Institute of Electrical Engineers, 33 West 39th Street, New York 18, N. Y.,* $3.50.

Methuen Monographs on Physical Subjects, available from John Wiley & Sons, Inc., New York: *Collision Processes in Gases* (4th ed.), by F. L. Arnot, $1.25; *An Introduction to Vector Analysis for Physicists and Engineers* (4th ed.), by B. Hague, $1.25; *Wave Filters* (3d ed.), by L. C. Jackson, $1.25; *X-ray Crystallographs* (4th ed.), by R. W. James, $1.25; *Atomic Spectra* (2d ed.), by R. C. Johnson, $1.25; *The Kinetic Theory of Gases* (3d ed.), by M. Knudsen, $1.25; *Applications of Interferometry* (4th ed.), by W. E. Williams, $1.25; *X-rays* (3d ed.), by B. L. Worsnop and F. Chalklin, $1.25; *Heaviside's Electric Circuit Theory* (2d ed.), by J. Josephs, $1.25; *Wave Mechanics* (6th ed.), by H. T. Flint, $1.25; *Atmospheric Turbulence* (1st ed.), by O. G. Sutton, $1.50.

PRODUCTS and MATERIALS

NEUTRON COUNTER TUBES

General Electric Co., 1 River Rd., Schenectady 5, N. Y. Two proportional counter tubes which are sensitive to slow neutrons have cathode walls of $\frac{1}{32}$-in. seamless steel tubing lined with enriched boron. Filled with argon-ethyl-ether gas, the BPA-63A has a sensitive volume of $1\frac{1}{2} \times 8$ in.; the BPA-T2B has a sensitive volume of $1\frac{1}{2} \times 12$ in. Efficiency is said to be 1.85%. At least half of the plateau is below 600 volts; average normalized plateau slope is less than 2.7% counting rate per % volt. All external high-voltage points are shielded both electrically and physically.

LABORATORY DRY BLENDER

The Patterson-Kelley Co., Inc., East Stroudsburg, Pa. Cylindrical shell of 0.187-in. Plexiglas, fused together at right angles to form a vee-shaped barrel, constitute the basic unit in a new dry blender designed for laboratory use. Four and eight quart barrels are interchangeable. A gearhead motor and chain drive are used to rotate the barrel at 32 rpm. Removable covers at each end of the barrel make all surfaces of the barrel easily accessible. Besides providing complete visibility of the blending action, the unit is said to provide a combined tumbling and rolling action. Height is 24 in.; base dimensions are 28×14 in.

MINIATURE GAMMA DETECTOR

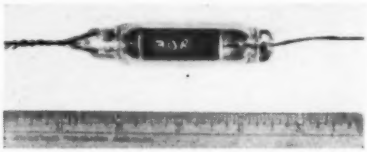
Instrument Division, The Kelley-Koett Mfg. Co., 139 E. 6th. St., Covington, Ky. Slightly larger than a king-sized pack of cigarettes—dimensions are $4\frac{3}{4} \times 2\frac{5}{8} \times 1\frac{1}{8}$ in.—the model K-550 gamma detector weighs only ten ounces. A hearing-aid type earphone is used to count pulses from a sub-miniature, 300-volt G-M tube. Normal background is approximately 12 cpm. Two 30-volt miniature batteries and a standard $1\frac{1}{2}$-volt flashlight cell are used in the power supply. Only control is an "on-off" switch.

SURVEY METER

Eclipse-Pioneer Division, Bendix Aviation Corp., Teterboro, N. J. Sensitive to both beta and gamma radiation, the type XD-793831-1 radiation survey meter is calibrated in three ranges: 0–20 mr/h, 0–2 mr/h, and 0–0.2 mr/h. Calibration controls are provided for each range. Earphones may be used for aural monitoring. The cast magnesium case has over-all dimensions of $9 \times 6 \times 3$ in. Weight is 5 lbs.

THICKNESS GAGE

Pratt & Whitney Division, Niles-Bement-Pond Co., West Hartford 1, Conn. The Beta Ray Continuous Gage uses strontium-90 or ruthenium-106 and an ionization chamber to determine the thickness or weight per unit area of thin strips of moving materials. With Sr^{90} the range of the gage is from 5 to 150 ounces per square yard; with Ru^{106} the range is 50 to 300 ounces per square yard. Readings are accurate to 1%. When used with the combination setter and control meter shown in the illustration, the gage will operate process control or alarm circuits.



VOLTAGE REGULATOR TUBES

Electronic Products Co., 111 E. 3rd St., Mt. Vernon, N. Y. Corona-discharge voltage regulator tubes with a current rating of 5 to 60 μa (100 μa absolute maximum) can be supplied for regulation points at 300, 325, 400, 700, 900, 1,000 and 1,400 volts. Accuracy of regulation as low as 0.1% over the current range can be obtained. The regulator tubes are available in four qualities, selected in accordance with the tolerance of regulation.

REGULATED POWER SUPPLY

Kepco Laboratories, Inc., 149-14 41st Ave., Flushing, N. Y. The model 315 voltage-regulated power supply provides a B supply continuously variable from 0 to 300 volts, a C supply continuously variable from 0 to -150 volts,

and a 6.3-volt, 5-amp a-c filament supply. The B supply will deliver up to 150 ma, regulated to 0.5% from 20 to 300 volts for all load variations and for line fluctuations from 105 to 125 volts. Delivering 5 ma, the C supply is regulated to 0.5% at 150 volts. Ripple is less than 5 mv, and low output impedance is claimed.

COMPOUND VACUUM PUMP

Kinney Manufacturing Co., 3614 Washington St., Boston, Mass. The model CVD 3534 compound vacuum pump employs an oil-seal pumping system. It has a free air displacement of 4.9 ft^3/min. It is claimed that the unit can produce an absolute pressure of 0.1 micron, operating from a ⅓-horsepower motor. The pump is less than 16 in. in height. No warm-up period is necessary before operation, according to the manufacturer.

MICROCHEMICAL GLASSWARE

Radiation Counter Laboratories, Inc., 1844 W. 21st St., Chicago 8, Ill. Calibrated in lambdas (one λ equals 0.001 ml), microchemical pipets can be supplied either "to deliver" or "to contain" the calibrated volume. There are 16 types available in capacities ranging from 1 to 500 λ. A pipet drier and cleaner is also available.

ELECTRICAL INDICATOR

Analytical Measurements, Inc., 585 Main St., Chatham, N. J. The Analascope is designed to measure and show continuously any phenomena that can be translated into electrical impulses. A 5-in. cathode-ray tube with long-persistence screen is used for displaying results. A two-decade precision potentiometer with a self-contained standard cell is provided for direct measurement of *p*H values from 0.001 to 15, and of voltages from 0.1 mv to 1.5 volts. An input attenuator of 1,000 megohms provides overlapping ranges of 1 μμa to 10 ma, and 1 mv to 100 volts per centimeter deflection.

COBALT-60 RENTAL

St. John X-ray Laboratory, Califon, N. J., has been authorized by the AEC to handle radioactive cobalt on a rental basis. Cobalt and other radioactive materials may also be purchased.

LITERATURE AVAILABLE

Mortar Grinder. Folder describes motorized mortar and pestle which requires little operator attention. *Fisher Scientific Co., Forbes St., Pittsburgh 19, Pa.*

Electronic Relay. Bulletin 2178 details a relay which has a power gain of 200 million and can handle loads up to 20 amp at 250 volts. *American Instrument Co., Inc., Silver Spring, Md.*

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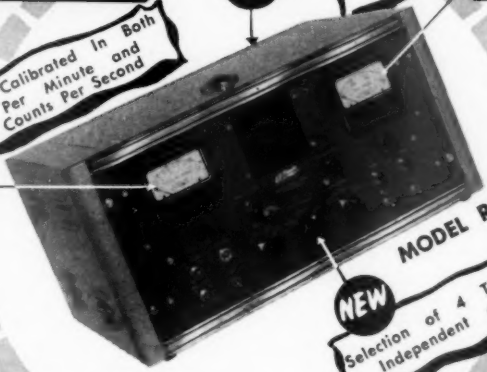

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REFLECTIONS

Luminescence Measurements

DEAR SIR:

In the recent paper by B. Cassen and L. Curtis on "Luminescence Measurement of Roentgen Dosage" (NU, Feb. '50), the authors compared their dosage rate for a beryllium window X-ray tube operating at 50 kv with the value obtained by me in 1945 for somewhat similar conditions.

Their reported value of the r/ma-min at 10 cm target distance is less than one fifth of the dosage rate obtained by me and since confirmed by other investigators. The authors conclude that my value is probably quite a bit too high, but offer no explanation for this discrepancy other than pointing out the difference in voltage-wave form; this, however, can account only for ~ 40 %.

It is the purpose of this communication to call attention to several factors which may explain the low dosage rate obtained by Cassen and Curtis. Let us first compare present available data:

	X-ray tube voltage	*Wave form (potential)*	*r/ma-min at 10 cm*
Cassen-Curtis	50 kvp	pulsating	239
Jennings*	"	"	1180
Day†	50 kv	constant	1440
Braestrup	"	"	1550

* W. A. Jennings. Physical aspects of the roentgen radiation from a beryllium window tube operated over the range 2–50 kvp for clinical purposes. (To be published in *Acta Radiologica.*)

† Personal communication, F. H. Day, National Bureau of Standards, Washington.

Part of this great discrepancy may be explained by the method of calibration used by Cassen and Curtis. They calibrated their instrument against a Victoreen thimble chamber. As has been shown by Day, such a chamber has a wavelength correction factor of as much as 2.0 for soft radiation.* Another possibility is the lack of proportionality between the photocell response and intensity. According to their Fig. 2, proportionality is established only up to about 8 μa, although according to their calibration the current must have reached $\sim 164\ \mu$a ($= \sim 164 \times 10^3$ r/min).

The authors report considerable divergence from the "inverse square law" when reducing the target distance. It is questionable, however, whether any general conclusions can be drawn from their data in this respect. The r/min at a given point should be independent of the orientation of the measuring device; yet in Fig. 1 of their paper there is a difference of as much as 35% in r/min for the exact same point on the center line, depending upon the plane of measurement.

CARL B. BRAESTRUP
City of New York, Dept. of Hospitals
New York

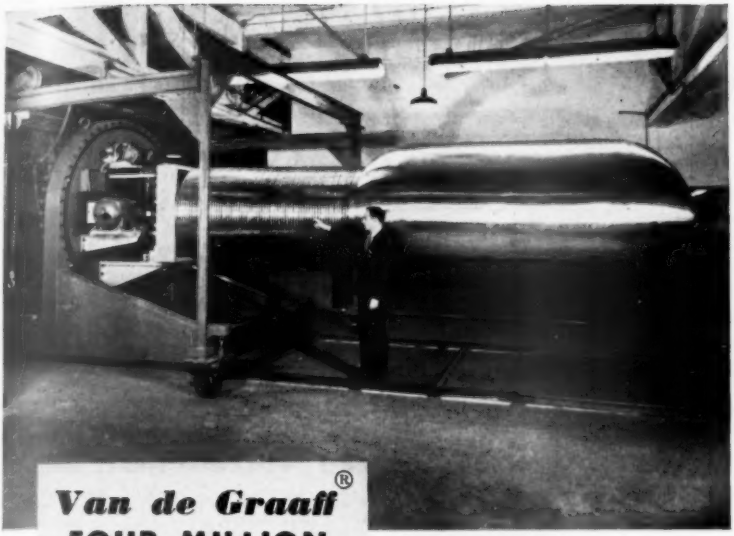
To which the authors replied: It is true our luminescence measurements give, with our particular tube and mode of operation, absolute values of roentgen output that are much lower than those quoted by Dr. Braestrup.

However, our conclusion that the output values, close to the beryllium window, are high is based solely on (1) Braestrup's value at 10 cm, and (2) the fact that the relative measurements made with our instrument show a failure of the inverse square law as the beryllium window is approached. There are several conceivable reasons to explain this failure, and further investigations are being made. We doubt very much that the apparent failure of the inverse square law is an artifact, as it is reproducible at low tube milliamperes.

We explicitly stated the possibility

(*Continued on page 96*)

* F. H. Day. Thimble-chamber calibration on soft X-rays, *J. Research Natl. Bur. Standards* **41**, 295 (1948).



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Nucleonic Events (*Continued from page 84*)

search Laboratories and president of the Pittsburgh Physical Society. In 1946, he was called on to do nuclear physics research at Oak Ridge.

MEETINGS

Conference and Symposium on "Ionospheric Physics"—Pennsylvania State College, State College, Pa., July 24–26

International Radiological Congress—London, England, July 24–30

British Association for the Advancement of Science (Annual Meeting)—Birmingham, England, Aug. 30–Sept. 6

American Chemical Society (118th National Meeting) and 6th National Chemical Exposition—Chicago, Ill., Sept. 3–8

Institute of Radio Engineers (West Coast Convention)—Long Beach, Calif., Sept. 13–15

National Electronics Conference—Chicago Ill., Sept. 25–27

Institute of Radio Engineers and American Institute of Electrical Engineers Conference on Electronics Instrumentation in Nucleonics and Medicine—New York, Oct. 23–25

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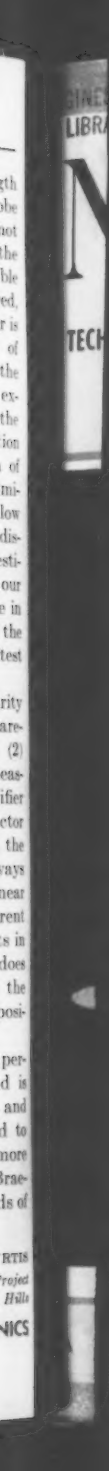
Reflections (*Continued from p. 92*)

of our basic assumption of wavelength independence of the luminescent probe as being only reasonable and not proved. All our comparisons of the probe with the Victoreen thimble chamber are with sufficiently filtered, hard radiation, so that the chamber is used within its ordinary range of applicability. The calibration of the probe to the soft radiation is an extrapolation of calibration with the harder radiation, which extrapolation depends on our basic assumption of wavelength independence of luminescence of a phosphor of very low atomic-number components, as discussed in our paper. We are investigating the necessity of modifying our assumption because of a difference in photoelectric absorption between the plastic pick-up and air for the softest components of the radiation.

In our procedure, (1) the linearity of the photocell response was carefully tested over the range used, (2) the maximum output current measured was 33.5 μa, (3) the amplifier gain and attendant calibration factor was changed several times during the course of the test in order to always keep the output current in a linear readable range, and (4) the apparent discrepancy of axial measurements in the two planes of measurement does not arise from an asymmetry of the pickup but from a small error in positioning the template.

Our probe is far from being a perfected measuring instrument and is subjected to further refinements and comparisons. We would be glad to have the opportunity of making more direct comparisons with Dr. Braestrup's as yet unpublished methods of measurement.

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